KNOWLEDGE ACQUISITION VERSUS SKILL DEVELOPMENT: PEDAGOGICAL CONSIDERATIONS FROM AN INTELLIGENT TUTORING PERSPECTIVE

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ABSTRACT
Intelligent Tutoring Systems (ITS) are traditionally developed within cognitive domain spaces that associate with problem solving and procedural application of knowledge. As such, much of the research and literature on pedagogical management in ITS environments is confined to managing cognitive impasses and misconceptions as they relate to declarative and procedural information within the context of a scenario/problem. A gap in the literature that needs to be addressed is how best to apply ITS methods in a skill development domain (i.e., a domain incorporating psychomotor task elements that require consistent and precise execution to meet task objectives). In this paper we present pedagogical guidelines as they relate to ITS coaching in a psychomotor task environment, and how those guidelines are informed through theoretical underpinnings of skill acquisition and techniques of practice. These guidelines will inform the design of skills-oriented tutoring systems and are useful constructs in defining requirements for skill-oriented ITS authoring tools.

Keywords: intelligent tutoring systems, psychomotor, skill acquisition, feedback, pedagogy

1. INTRODUCTION

Recent interest in the application of Intelligent Tutoring Systems (ITS) in psychomotor skill domains has raised fascinating questions centered on pedagogy. With a preponderance of ITS literature situated within cognitive domains that focus on problem solving and knowledge application, much of the findings with respect to instructional management do not apply outside those problem types. For this reason, it is important to re-conceptualize the role of ITS pedagogy in skill domains that involve muscle movement and hand-eye coordination.

In this paper, we tease apart the components as they relate to knowledge acquisition versus skill development, and how the identified distinctions should drive pedagogical configurations as they adhere to instructional design and learning theory. Following, guidelines will be presented for feedback management and coaching in psychomotor skill related domains. These guidelines will be informed initially through theoretical underpinnings of kinesiology, sports psychology, and cognitive psychology. The outcome will be a set of competing pedagogical approaches that vary the level of support an ITS will provide, with distinctions in learner individual differences driving which approach to enact. These approaches will ultimately require empirical evaluations to gauge their utility in applied settings.

2. KNOWLEDGE ACQUSITION VERSUS SKILL DEVELOPMENT

For the purpose of this discussion, we distinguish between *knowledge acquisition* and *skill development*.

2.1. Knowledge Acquisition Basics

In its most basic theoretical form, knowledge acquisition associates with the process of perceiving, processing and storing new information in memory. Moreover, this involves the ability for knowledge retrieval when the situation warrants its application (Baddeley 2004).

Knowledge is typically categorized as declarative (memory in the form of concepts, facts, or episodes) or procedural (ability to perform tasks through proceduralized associations), with an encoding in memory that proceduralizes knowledge following multiple applicable uses of that information (Anderson 1982). To further break down knowledge acquisition, Nunes and Karpicke (2015) present the following guidelines based on how knowledge is organized and how learning materials should be created: (1) process material semantically, (2) process and retrieve information frequently, (3) learning and retrieval conditions should be similar, (4) connect new information to prior knowledge whenever possible, and (5) create cognitive procedures as procedural knowledge is better retained in memory and more easily accessible. These principles associate with how information is effectively stored in memory for easy retrieval when the time warrants its application. The development of human expertise is attributed to knowledge stored within schemata where simple ideas are combined or chunked into more complex ones, not through the processing and arrangement of elements unorganized within long-term memory (Van Merriënboer and Sweller 2005).

Based on these foundations, ITSs are traditionally developed through the application of models that target the domain knowledge space based on the declarative and procedural properties required to solve defined problem sets. There are numerous modeling approaches applied over the years (e.g., Bayesian, neural nets, etc.; see Pavlik, Brawner, Olney and Mitrovic 2012 for a thorough review), each designed for the purpose of tracking learner progression and to identify any impasses or misconceptions in their procedural understanding of that topic space. In addition, these systems are designed with pedagogical underpinnings driving problems/scenario selection and guidance/feedback variations based on individual differences during a practice event (Kulik and Fletcher 2016, Woolf 2009). What is missing in the ITS community is an extension of these methods to account for physical properties of a domain space that associate with skill development, both from the modeling perspective, which is required to inform contextualized assessments to drive feedback and remediation, along with pedagogical considerations that adhere to learning psychomotor skills that go beyond a cognitive understanding of what to do.

2.2. Skill Acquisition Basics

As a defining characteristic, we associate physical skill development as an interplay between cognitive understanding (declarative and procedural) and psychomotor application, whereas the utility of skill requires gross control of fine motor movements when performing a task. This association is critical when conceptualizing the role of ITS in military contexts, as majority of the tasks performed across the spectrum of warfare incorporate physical interactions, with varying degrees of complexity, frequency and duration (Department of the Army 2011).

There are common tenets expressed in the literature associated with learning a new physical skill. The first and foremost is that experience and practice trumps all, with a definitive association between time spent in practice and improvement in proficiency (Côté, Baker and Abernethy 2007). However, simply practicing a skill over multiple repetitions seldom leads to expert performance. Without formalized structure around the type of practice and the feedback received, performance eventually plateaus below what is considered optimal/expert (Ericsson 2008).

Developing a new skill follows three primary phases of acquisition: (1) cognitive novice phase where an individual tries to understand the cognitive and physical requirements of the activity to generate actions while avoiding errors; (2) the associative intermediate phase where focused attention on task performance is no longer required and noticeable errors become increasingly rare; and (3) the autonomous expert phase where the execution of a skill becomes automated with minimal cognitive and physical effort (Goldberg 2016, Fitts 1967). From the coaching perspective, the most critical stage for directive instruction is in the initial cognitive phase where mental models are being established that link motor control to objective outcomes. How can an individual modify or reinforce behavior if there is no way to effectively link actions to performance? During this critical phase of learning, behavioral tendencies are established and schemas are formed in memory, making feedback to instill proper habits critical. In the traditional sense, a coach/instructor with knowledge in the domain will closely observe a learner, identify errors in his or her behavior as determined by a performance outcome, and provide feedback to correct errors and reinforce proper technique. This process is repeated until evidence is acquired that supports stable development of skill execution. The goal is for an ITS to mimic this interplay in an automated fashion.

2.2.1. Deconstructing a Skill into Fundamental Components

Utilizing technology to facilitate these described inference procedures is challenging. It requires perceptual oriented data corresponding to behaviors that an expert human would assess, and the application of models to determine how the captured data relates to a representation of desired behavior. This proposed process warrants a deconstructed task analysis to break a skill set down into a hierarchical structure of varying fundamental concepts and procedural applications.

This representation is critical as it becomes the foundation by which an ITS is developed. In other words, identifying the fundamental components of a task, and the skill sets required to successfully perform the task, informs the design of instructional materials and practice opportunities that target specific subsets of skills to drive an individual’s acquisition curve. This top-down approach also establishes criteria for measuring performance and designating thresholds for gauging success.

In terms of relating what’s already been discussed to a real-world example, take the domain of rifle marksmanship. When someone is attempting to learn how to shoot a rifle for the first time, the initial approach to instruction is focused on a set of fundamentals. These fundamentals provide a foundation of required skills to successfully perform as an elite marksman. In this instance you can decompose marksmanship into four physical fundamental skills: (1) body stability, (2) breathing, (3) breath control, and (4) site alignment. Each of these break-down further into a set of sub-skills that ascend in complexity as you progress through practice opportunities (e.g., body stability in prone, body stability while kneeling, body stability while standing, body stability while on the move, etc.).

The desired end state is the development of muscle memory to automatically perform a task without dedicating cognitive function to make it happen. When you establish automated execution of fundamental behaviors, then an individual can progress to more complex scenarios requiring advanced application of a skill (e.g., hitting a moving target). This is followed by practice opportunities to combine the application of disparate skill sets (firing a rifle and communicating tactical decisions) for more enriched scenarios to better instill autonomous execution.

This analogy can associate with almost all psychomotor domains of instruction, regardless if its association with job-related activities or athletics. Each domain can be deconstructed into a set of fundamental components that are performed when a situation warrants their execution. The goal of an automated ITS is to establish models of fundamental behaviors to make the assessment space manageable and to establish training and practice opportunities that target the development of specific fundamental skill sets.

2.2.2. The Link between Practice and Skill

While there is a large base of research focused on understanding how conditions of practice, including variability, distribution, and segmentation influence performance and retention of skill (see Lee, Chamberlin and Hodges 2001 for a thorough review), each practice event provides critical data points from which initial ITS development should be based.

Anders Ericsson's theory of deliberate practice highlights the following attributes of an effective practice event: (1) the event is designed to improve performance; (2) the individual has the ability to repeat the application over multiple trials; (3) the task requires high mental engagement; and (4) feedback is continuously made available that is designed to serve in a coaching capacity (Ericsson, Krampe, and Tesch-Römer 1993; Ericsson 1996). While these attributes provide generalizable guidelines when constructing specific scenarios and interactions, they do not provide measureable constructs that can be used to guide actual scenario development. Combining these guidelines with a task analysis provides the pedagogical building blocks to configure specific interactions to be managed by the ITS. The goal is to balance challenge with guidance, as outlined in the Zone of Proximal Development (Vygotsky 1987), so as to promote skill development that retains over time and transfers to novel situations.

In addition, there are three further distinctions that must be addressed to support self-regulated deliberate practice events: (1) the content and material applied in support of the practice events, (2) the sequence of interactions leading up to and following a practice event, and (3) the coaching approach applied within that practice event. As the concept of psychomotor ITSs are framed within a self-regulated learning model (Department of the Army 2011), the initialization of a practice event is preceded by the delivery of upfront instructional materials that prepares an individual learner for the set of tasks they will be asked to perform. In the following sections, we highlight the role of ITS technologies to facilitate the sequence of interaction that focuses on self-regulated skill development. We present the considerations in place that are applied to configure the pre-practice materials (i.e., multimedia content and other forms of instruction), the practice event itself with real-time assessment and feedback functions, followed by an after-action review component that serves as a form of remediation.

3. ITS APPLICATION FOR SKILL DEVELOPMENT

Each factor presented above is critical when determining the implications of using ITSs to replace human counterparts to train psychomotor skills. They should act as guiding principles when establishing practice opportunities within an ITS framework, whereas each attribute serves as a validation check to ensure the training experience is grounded in human performance heuristics. To base the discussion, we present design considerations as they adhere to the U.S. Army Research Laboratory's Generalized Intelligent Framework for Tutoring (GIFT; Sottilare, Brawner, Goldberg and Holden 2013).

3.1. Generalized Intelligent Framework for Tutoring

GIFT is an open-source architecture project with an evolving set of standardized software modules for authoring and configuring adaptive training materials across an array of supported training applications. Each application represents externally developed systems designed for educational and training purposes, each integrated through GIFT's gateway module for assessment and pedagogy practices. GIFT provides the ability to apply common modeling techniques against application generated data to inform real-time assessments in any supporting system, including game-based applications (Goldberg, Brawner, Holden and Sottilare 2012, Shute, Ventura, Small and Goldberg 2013) and now psychomotor supported simulation environments (Bell, Brown and Goldberg 2017, Goldberg, Amburn, Ragusa and Chen, 2017).

With integration technologies in place, GIFT also provides the mechanisms for configuring a learner's experience within and across disparate training applications within a single lesson experience (Goldberg, Davis, Riley and Boyce 2017). In this instance, GIFT provides a platform to enable the interchange of multiple training environments to instruct a single set of concepts. This highlights the open robustness of the architecture in that it can be repurposed for any conceivable domain, assuming the content and assessments are in place to support lesson creation. This also shows how GIFT promotes interoperability between platforms, as the lesson could incorporate multiple training environments to manage the attainment of multiple complimentary skill sets.

A driving requirement within the GIFT program is providing a set of tools to Army training developers that enable the creation of customized ITS applications outside of laboratory settings. For this purpose, a focus of the GIFT program is establishing pedagogical frameworks and authoring workflows that guide the development experience and ensures sound learning science principles are being leveraged. This entails applying instructional management principles and theories into the interactions supported when authoring lessons in the GIFT authoring tool. A GIFT lesson is configured at two levels: (1) the macro level where a structure of GIFT course objects are established that dictates the overall sequence a learner will experience, and (2) the micro level where each course object is configured to designate the interactions within, the assessments applied, and the pedagogical logic designated for managing assessment outcomes. Each of these associations will be discussed, with a focus on extending GIFT's pedagogical logic to support theory derived from skill acquisition and psychomotor learning.

3.2. ITS Pedagogy at the Macro Level

As an organizing function, instructional design models of psychomotor skill progression should be incorporated to guide the interactions and practice events managed by the ITS. A model is required to structure and guide configured interactions where specific pedagogical considerations can be authored within. The goal is to apply a theoretically based schema that dictates what type of lesson/training material should be applied at what time in support of self-regulated skill development.

An example of this nature developed for cognitive associated problem spaces is GIFT's Engine for Management of Adaptive Pedagogy (Goldberg et al. 2014, Goldberg, Hoffman and Tarr 2015). The EMAP serves as the first domain-independent closed-loop model where an instructional design approach outlined in David Merrill's component display theory was modeled as an organizational schema to reference learning interactions (see Figure 1). In its most simplistic form, the EMAP guides an author in establishing content to cover the declarative and procedural rules of a domain with examples provided, recall oriented questions to act as checks on learning to confirm comprehension, and practice opportunities supported by external applications with assessment and guidance configured. This structure is encapsulated in GIFT's Adaptive Courseflow course object.

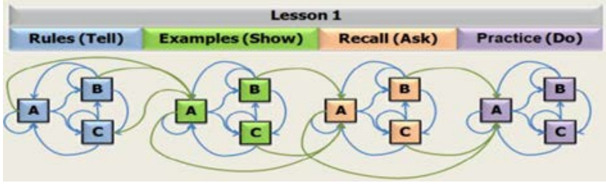

Figure 1. GIFT's EMAP highlighting the sequence and flow of instruction and remediation.

In Brown, Bell and Goldberg (2017), the authors review five fundamental theories related to psychomotor learning, with search results identifying a synthesized theoretical model to feed ITS development efforts (see Table 1). The project, the Psychomotor Skills Training Agent-based Authoring Tool (PSTAAT), is leveraging this synthesized model to build a new course object designed for psychomotor skill domains. The PSTAAT applies workflows to guide an ITS developer in configuring materials within the model components of observation, imitation and practice, with adaptation practices enabled throughout.. Based on architectural foundations established during EMAP development, the PSTAAT serves as an abstraction of that model in that it applies the theoretical framework described in Table 1 as the building blocks for system configuration. To simplify the cognitive load with authoring a psychomotor ITS, the PSTAAT incorporates an intelligent agent that provides guidance and examples during the design and configuration process with built-in tools to establish modeling techniques for assessment purposes.

Table 1. Synthesized skills domain model, derived from Brown, Bell, & Goldberg (2017)

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.

3.3. ITS at the Micro Level

At runtime, an ITS operates on three primary models: (1) a model of the task being performed, (2) a model of the learner being instructed, and (3) a model of pedagogy and instructional practice as it relates to the domain and learner being instructed. The lynch-pin of these systems is the ability for an ITS to gauge performance as it relates to the assessments being captured during interaction. The pedagogical reasoning in an ITS is dependent on the information it has as it relates to the context of the scenario being performed, and the environment from which the interaction is taking place (Goldberg 2017).

As mentioned above, each domain can be deconstructed into a set of fundamental components that are performed when a situation warrants their execution. The goal of an automated ITS is to establish models of fundamental behaviors to make the assessment space manageable. While the assessment space of a domain is defined around a set of concepts and objectives, it is inherently dictated by the data one can collect.

3.3.1. Understanding the Assessment Space

There are two fundamental applications of domain modeling in ITS environments. These approaches establish how learner interaction will be assessed, and how a system responds pedagogically is dependent on how the assessment is implemented. In the area of ITS for skill development, the two modeling applications we focus on are (1) expert models and (2) buggy-libraries.

The goal of these models is to classify real-time performance; with a granular enough representation to dictate what objective and/or concept requires feedback and/or remediation.

3.3.2. Expert Models vs. Buggy-Libraries

Expert models are statistical representations of ideal behavior within a designated scenario or problem. In cognitive problem-spaces, common models are based on model-tracing approaches that can track a learner's actions as they relate to procedural steps, and identify impasses and misconceptions when a deviation from a desired path is recognized. Modeling techniques continue to evolve over time, with new methods capturing more diagnostic information to better inform feedback practices, but these methods do not translate to physical task spaces where assessment is not bound by well-defined procedural steps.

For psychomotor skill domains, current practices of expert modeling leverage task performance data feeds collected within a simulated or augmented environment (Goldberg 2016). The model is dependent on the data produced during the interaction and the characteristics of the task being performed. In initial efforts, the assessment space was based on descriptive models of behavioral signals over specified windows of time surrounding a designated event within the practice scenario (e.g., modeling trigger data for two seconds leading up to a shot). Models are established on expert data sets, with thresholds established based on observed model properties.

Current efforts to support these models in GIFT require configurations of sensor inputs to inform assessment state representations. The sensor inputs are mapped to fundamental concepts that data feed supports. To aid in this authoring process, PSTAAT provides a simpler abstraction of the sensor configurations, so that one could adjust the performance threshold expectations at different phases of instruction. This supports transition between imitating/practicing as well as could enforce difficulty level if the activity warrants it as an individual progresses in their skill acquisition curve.

As the initial expert models generated can be used to dictate what an individual is doing differently, these models do not have the ability to accurately determine what is truly causing differences in performance, which limits the system's ability to provide detailed feedback.

3.4. Building a Closed Loop System

With assessment models in place, the goal is to develop a completely closed-loop system that supports self-regulated skill development based on individual performance and their progression within a skill development curve. The assessment models are designated to specific application oriented exercises that specify what action a learner is to take. These actions are represented through an ontological breakdown of the task features and their derived concepts. The models designed should map directly to each concept representation, so that during the execution of a task, the system is able to monitor and grade performance as it relates to the standards built within the models' scoring logic. This domain representation is established and ontologically translated to the remaining ITS modules used to drive coaching and personalization. With performance scores available, these states are communicated to a learner model to create a full picture of the learner state (i.e., includes information as it pertains to performance, individual differences, and affective response if available). A performance state update, classified as above-expectation, at-expecation, below-expectation, and unknown at a concept by concept basis, are the events communicated to the learner module. The system is observing transitions in performance so as to drive pedagogical interventions when shifts in learner state trigger predefined actions.

With a closed-loop capability in place, and a theoretical foundation to configure lesson interaction, the next function in developing a generalized GIFT course object for training psychomotor skills is establishing pedagogical principles that drive personalization practices. The goal is to create training experiences that adhere deliberate practice. In the remainder of the paper, we will present guidelines, along with a use case of application, that synthesize elements of deliberate practice with the synthesized model of psychomotor skill development to create a highly adaptive training experience that personalizes feedback and remediation based on real-time performance and individual characteristics.

3.5. ITS and Post-Exercise Remediation

Following the completion of a problem, scenario, or exercise, a well-designed ITS contains the assessment and performance data required to drive post training events that target deficiencies in ability. In essence, a system can prescribe follow-on exercises that directly instruct specific concepts or misconceptions detected during a trainee's interaction.

Current components in GIFT support customized remediation paths based on logic configured within the EMAP. Development efforts are extending this rule-based approach by implementing stochastic modeling processes that adhere to an additional model of interaction based on Chi's (2009) learning activity framework that categorizes activities as being constructive, active, or passive (CAP). This framework is providing the theoretical foundation to apply Markov Decision Processes (MDPs) for the purpose of targeting individualized learning materials following an assessment event based on individual differences and the needs of a given trainee (Rowe et al. 2015). In an effort to use this existing infrastructure, an additional goal of the PSTAAT tool is to incorporate the CAP components in a physical skill domain, which will require reconceptualization on the type of activities to configure based on task characteristics and the environment from which the training event takes place.

4. PEDAGOGICAL GUIDELINES FOR SKILL DEVELOPMENT

There are two levels of instructional considerations when developing an ITS for a psychomotor skill domain. These include the application of pedagogical design theories that adhere to ways in which individuals learn a new skill, and the use of sports psychology and coaching practices that associate with improvement-oriented feedback and motivation management. To guide the discussion within this section, we will present a use case to ground the defined guidelines with contextualized examples.

4.1. The Adaptive Marksmanship Trainer (AMT)

As a means to provide a grounding function for the guidelines presented below, we will use the AMT use case to give specific examples of pedagogical strategy implementations. The AMT is a well-suited exemplar, as it has all the components in place to provide individualized assessment on the functional elements of firing a rifle (Goldberg, Amburn, Ragusa and Chen 2017, Department of the Army 2016). This capability is enabled through sensor technologies embedded within a simulated carbine rifle (e.g., barrel movement, trigger pressure, and breathing waveform), and associated models of expert behavior as deemed through a cross-fold validation descriptive modeling technique. With a closed-loop function, the AMT can collect shooter performance and behavior data in real-time, process that data to compute behavioral metrics, and apply those metrics within established models to determine if particular behaviors were being erroneously executed.

Table 2. Pedagogical guidelines embedded within synthesized skills domain model to inform personalization practices.

	Skill Acquisition Phases		
	Cognitive	Associative	Autonomous
Observing	Learner observes expert task performance with provided narrative on fundamental application of behavior.	Learner observes expert task performance and describes behavior in own words.	Learner observes own behavior and provides subjective interpretation of technique and application.
Imitating	ITS provides focused practice opportunities designed to elicit imitation of specific micro-behaviors (e.g., exercise focused solely on trigger control, without any other component of marksmanship addressed)	Imitation phase for associative learner is focused on process incorporating all fundamental behaviors required to complete task. Focus is on task set-up, rather than execution.	Imitation phase for autonomous learner is represented in practice, where trend analysis is used to determine consistent imitation of proper technique while practicing.
Practicing/ Adapting	The practice/adapt loop is the primary component of an ITS pedagogical function. Coaching is process-oriented, with focus on repetition and exhibited consistency through data-driven assessment.	Coaching is error-based, as procedural process is in associative phase. Adaptation is specific to behavioral models, with buggy-library as preferred mechanism.	Coaching is error-based, but provided in After-Action Review format, with focus on behavior trends as learner observes their own performance outcomes.

Current logic in GIFT can monitor behavior on a shot-by-shot basis, where performance is derived on the completion of a 5-shot group (i.e., the trainee executes five consecutive shots with the goal of striking the same location on a target with each round). Following the 5-shot group GIFT computes performance measures and classifies behavioral assessments (i.e., breathing, trigger control, and body stability). If performance is below a designated threshold, the behavioral models are applied to decide on which element of the task to remediate. The current AMT will provide feedback on a selected fundamental, with the same material provided to each trainee, regardless of experience and current skill level. An overarching goal is to extend the current AMT to support a more robust self-regulated experience. This includes applying the PSTAAT task model to drive training interactions, and to develop further pedagogical guidelines that personalize and adapt a training event as skill progression is observed.

4.2. Coaching Considerations for Psychomotor Skills

A major distinction this work addresses is the role pedagogy plays in skill development across the three phases of acquisition. Just as in any instructional setting, the level of support and challenge of the task should be adjusted to the needs of a given individual. In this instance, learning a psychomotor skill involves a number of elements, including: (1) knowing at a declarative and procedural level what one should do, (2) knowing at the application level how to apply physical actions to meet a task objective, (3) making the link between physical action and cognitive understanding, enabling an adaptation loop on mental schemas as one continues to perform a task, and (4) managing emotional and affective states related to performance outcomes and task characteristics/dependencies (Colvin 2008, Gladwell 2008).

From here, rather than apply common scaffolding techniques applied in ITSs, we employ a psychomotor pedagogical model grounded in sports psychology. This theoretical basis introduces new techniques related to the development of expertise, with elements of scheduling, coaching, and repetitive practice opportunities (Ericsson 2008). While these high-level descriptors are defined in common human performance oriented literature, we focus on a further layer of decomposition as it relates to coaching in an ITS. For this purpose, we focus on two forms of feedback support, process-oriented and error-oriented. Following the breakdown of these support functions, we describe how all the macro- and micro-adaptive functions are combined, along with rules for skill development progression, to create an advanced psychomotor training experience using ITS technologies.

4.2.1. Process-Oriented Coaching

The foundation of a process-oriented coach is focused on instilling a proceduralized set of fundamental actions that should be conducted when performing a task. From a pedagogical perspective, this approach to instruction is most appropriate for novices learning a new set of skills. It is in this instance where performers are most likely to commit an abundance of errors as it relates to the process of executing a task. While an ITS should be developed with models in place to detect errors in skill performance, during initial skill acquisition, the primary focus of instruction should be centered on process and technique, rather than reactive to specific errors being observed. Rather than the system directing the learner’s attention to a specific violation, the ITS should log the error information but apply pedagogy that reinforces specific fundamental principles that a learner needs to master.

In the example of the AMT system, there are multiple models in place to determine if a learner is properly executing fundamental behaviors while firing a rifle. While these models include diagnostics to provide focused coaching on specific errors, this approach to pedagogy should be postponed until that learner is deemed to be in the associative phase of acquisition. For novice learners, the models might determine that the individual has poor body stability and is quick on the trigger. While the ITS can provide feedback directly linked to those errors, the approach applied by expert instructors aims to instill process over behavior. The errors in fundamental are noted, but the coaching approach focuses at the process level of doing everything correctly in unison rather than focusing on a specific element of the task.

4.2.2. Error Response-Oriented Coaching

Error-response oriented coaching is a form of feedback support that is complementary to process-oriented coaching. This kind of feedback is activated by deviations detected during skill performance, and it is intended to draw a user’s attention specifically to that error. This approach to coaching is most effective in the associative phase of skill development (see Table 2), as mental schemas of proper execution are already established, yet errors in technique are consistent. In these instances, it is important to focus attention on specific elements of behavior. Rather than harp on procedure, feedback should be applied to link a specific function of their behavior with the observed performance outcomes. The goal is to create micro corrections in their application so as to build a connection between physical action and cognitive understanding (Kim, Dancy, Goldberg and Sottilare 2017). This varies from process-oriented coaching as it requires specific feedback strings or content (e.g., videos, slides, etc.) that is linked to each fundamental component modeled within that task. It is in this portion of the coaching paradigm within ITSs where the CAP approach described above can be instantiated within.

4.3. Bringing it All Together

With a synthesized task model of psychomotor learning in place, along with mechanisms to track progress within training as it relates to the phases of skill acquisition, and some high-level pedagogical guidelines based on process and error, the building blocks are in place to create a customized training experience at the individual level.

This is captured in Table 2, with specific references within that associate with the AMT use case. Balancing observation, imitation, and practice with varying degrees of complexity as one progresses provides the foundation for any psychomotor ITS.

Moving beyond the AMT use case, there are some assumptions related with the implementation of the approaches described. The primary assumption is that the task environment produces data sources at a granular enough level to drive assessment methods on fundamental components captured within a task analysis.

5. CONCLUSIONS

Rebranding ITS applications to support physical skill development in psychomotor domains requires new pedagogical principles to drive instructional design and coaching methods. In this paper, we present initial high level guidelines related to activity types and feedback strategies as they relate to a synthesized model of skill development and the activities that occur within. While research is required to provide empirical evidence of these guidelines, they provide a good starting point to establish a theoretical basis around. An advantage of applying these methods within GIFT is the nature in which GIFT can serve as a testbed to configure controlled experimental conditions to determine pedagogical effect on performance and skill retention.

REFERENCES

Anderson, J. R., 1982. Acquisition of a cognitive skill. Psychological Review, 89, 369-406.

Baddeley, A. D.,1995. The psychology of memory. In: A. D. Baddeley, B. A. Wilson, F. N. Watts eds. Handbook of Memory Disorders. New York: Wiley and Sons, 3-25.

Bell, B., Brown, D. and Goldberg, B., 2017. Focused authoring for building GIFT tutors in specialized domains: a case study of psychomotor skills training. Proceedings of 5th Annual GIFT Users Symposium, Orlando, FL.

Brown, D., Bell, B. and Goldberg, B., 2017. Authoring Adaptive Tutors for Simulations in Psychomotor Skills Domains. Proceedings of MODSIM World 2017. Virginia Beach (Virginia, USA).

Colvin, G., 2008. Talent is overrated: what really separated world-class performers from everybody else. London, England: Penguin Group.

Côté, J., Baker, J. and Abernethy, B. 2007. Practice and play in the development of sport expertise. In: R. Eklund and G. Tenenbaum, eds. Handbook of Sport Psychology. Hoboken, NJ: Wiley, 184-202.

Department of the Army, 2016. Rifle and carbine training circular (TC 3-22.9). Washington, D.C.: Army Publishing Directorate.

Department of the Army, 2011. The U.S. Army Learning Concept for 2015. Fort Monroe, VA.

Desmarais, M. C. and Baker, R. S., 2012. A review of recent advances in learner and skill modeling in intelligent learning environments. User Modeling and User-Adapted Interaction, 22(1-2), 9-38.

Ericsson, A., 1996. The road to excellence: The acquisition of expert performance in the arts and sciences, sports, and games. New York, NY: Psychology Press.

Ericsson, K. A., 2008. Deliberate practice and acquisition of expert performance: a general overview. Academic Emergency Medicine: Official Journal of the Society for Academic Emergency Medicine, 15(11), 988-994.

Ericsson, K. A., Krampe, R. T., and Tesch-Römer, C. ,1993. The role of deliberate practice in the acquisition of expert performance. Psychological Review, 100 (3), 363-406.

Fitts, P. M. and Posner, M. I., 1967. Human Performance. Belmont, CA: Brooks/Cole Publishing.

Gladwell, M., 2008. Outliers: The story of success: Hachette, UK.

Goldberg, B., Brawner, K. W., Sottilare, R., Tarr, R., Billings, D. R. and Malone, N., 2012. Use of Evidence-based Strategies to Enhance the Extensibility of Adaptive Tutoring Technologies. Proceedings of Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC), Orlando (Florida, USA).

Goldberg, B., Brawner, K. W., Holden, H. and Sottilare, R., 2012. Adaptive Game-Based Tutoring: Mechanisms for Real-Time Feedback and Adaptation. Proceedings of DHSS 2012, Vienna (Austria).

Goldberg, B., Hoffman, M. and Tarr, R., 2015. Authoring instructional management logic in GIFT using the engine for management of adaptive pedagogy (EMAP). In: R. Sottilare, A. Graesser, X. Hu and K. Brawner, eds. Design Recommendations for Intelligent Tutoring Systems: Authoring Tools: Volume 3. Aberdeen Proving Grounds: U.S. Army Research Laboratory.

Goldberg, B., 2016. Intelligent Tutoring Gets Physical: Coaching the Physical Learner by Modeling the Physical World. Proceedings of 10th International Conference on Foundations of Augmented Cognition: Neuroergonomics and Operational Neuroscience-Vol. 9744. July 19-21, Toronto (Ontario, Canada).

Goldberg, B., Davis, F., Riley, J. M. and Boyce, M. W., 2017. Adaptive Training across Simulations in Support of a Crawl-Walk-Run Model of Interaction. Proceedings of the 11th International Conference on Augmented Cognition. July 12-14, Vancouver (British Columbia, Canada).

Kim, J. W., Dancy, C., Goldberg, B. and Sottilare, R., 2017. A Cognitive Modeling Approach-Does Tactical Breathing in a Psychomotor Task Influence Skill Development during Adaptive Instruction? Proceedings of International Conference on Augmented Cognition, Vancouver (British Columbia, Canada).

Kulik, J. A. and Fletcher, J., 2016. Effectiveness of intelligent tutoring systems: A meta-analytic review. Review of Educational Research, 86(1), 42-78.

Nunes, L. D. and Karpicke, J. D., 2015. Retrieval-based learning: Research at the interface between cognitive science and education. In R. A. Scott & S. M. Kosslyn (Eds.), Emerging trends in the social and behavioral sciences. West Lafayette, Indiana: John Wiley & Sons, Inc.

Pavlik, P., Brawner, K., Olney, A. and Mitrovic, A., 2012. A review of student models used in intelligent tutoring systems. In: R. Sottilare, A. Graesser, X. Hu and H. Holden, eds. Design Recommendations for Intelligent Tutoring Systems - Volume 1: Learner Modeling. Aberdeen Proving Grounds, MD: U.S. Army Research Laboratory, 39-67.

Rowe, J., Mott, B., Lester, J., Pokorny, B., Peng, W. and Goldberg, B., 2015. Toward a modular reinforcement learning framework for tutorial planning in GIFT. Proceedings of Generalized Intelligent Framework for Tutoring (GIFT) Users Symposium (GIFTSym3). Orlando (Florida, USA).

Shute, V., Ventura, M., Small, M. and Goldberg, B., 2013. Modeling student competencies in video games using stealth assessment. In: R. Sottilare, A. Graesser, X. Hu and H. Holden, eds. Design Recommendations for Intelligent Tutoring Systems, Volume 1: Learner Modeling. Aberdeen Proving Grounds, MD: Army Research Lab, 141-152.

Sottilare, R., Brawner, K. W., Goldberg, B. and Holden, H., 2013. The generalized intelligent framework for tutoring (GIFT). In: C. Best, G. Galanis, J. Kerry and R. Sottilare, eds. Fundamental Issues in Defense Training and Simulation. Burlington, VT: Ashgate Publishing Company, 223-234

Van Merriënboer, J. J. G. and Sweller, J., 2005. Cognitive load theory and complex learning: Recent developments and future directions. Educational Psychology Review, 17(2), 147-177.

Vygotsky, L., 1987. Zone of proximal development. Mind in society: The development of higher psychological processes, 52-91.

Woolf, B. P., 2009. Building intelligent interactive tutors: Student-centered strategies for revolutionizing e-learning. Burlington, MA: Morgan Kaufmann.

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