Motivation

Educators from different institutions and programs often face similar challenges: they must teach a significant level of required, standardized, knowledge. Likewise, effective instructors work to increase student time-on-task, encourage participation from a broad range of students of different backgrounds and various levels of preparedness, while working to develop critical life-long learning skills. In K-18 education, the pressure to do more with less, and to maintain high levels of accountability require that any innovative tool introduced into a curriculum is highly cost-effective, adaptable, learner centered, provides measurable assessment results, and is relatively easy for faculty to use.

Serious games have significant pedagogical potential as they provide immersive, engaging and fun environments that require deep thinking and complex problem solving within a construct of overcoming obstacles and challenges. They create interactive student-centered environments rather than a passive content-centered classroom environment. This allows students to create a personalized learning experience, progressively incorporating new knowledge and scaffolding it into what they already know. The variability within this interactive environment permits students to work on lower-level tasks repeatedly as they develop broader analytical skills and progress to complete the game objectives. Because each student is able to engage course-based material at his or her own pace; underprepared or at-risk students can focus on needed skills at their convenience. Feedback is frequent and immediate, thereby reinforcing mastery of fundamental skills required for advancing further into the game.

Fundamentally integrating serious games into curricula, i.e., creating game-based curricula, encourages practice and mastery rather than rote memorization. Game-based curricula will stress strategic learning pushing students to practice further transference of their knowledge to more complex scenarios over the course of a semester. Inserting a game environment into a curriculum creates a highly motivating learning environment; it draws on students’ sense of fantasy and amusement; it is self-directed, appealing to individual student’s curiosity; and it is a continuous challenge wherein any existing tasks or knowledge will appear incomplete, inconsistent or incorrect, thereby challenging a student to continue and foster deeper levels of learning.
Research Goals

The research goals for our project are:

- **Rigorous, interdisciplinary meta-model foundation.** A meta-model is needed to integrate educators’ objectives (e.g., curricula development, learning objectives, assessment, accreditation,...) and game engineering objectives (e.g., game progression, rewards,...) at a fundamental level.
- **Widely applicable.** Games can be developed to address diverse educational topics (e.g., STEM, humanities) and environments (e.g., K-12, college, professional development training), both domestically and internationally.
- **Flexible curricula adoption.** Games can be developed with variations in duration, scope, and depth to fit into many curricula. For example, very short mini-games with clickers can be used to augment a traditional lecture or tutorial session; more comprehensive games can serve as supplements to e-learning modules or as stand-alone course content.
- **Comprehensive curriculum adoption.** One common limitation of game-based learning is that games tend to narrow in scope or function within any given curriculum. Sometimes a chain of different, often commercially available, games, have been strung together to create a game-based curriculum. The development of a meta-game that allows for increased continuity of a student player within a collection of integrated games that can be played across content subjects over the course of an entire semester would be more effective than smaller, specified games that only reinforce one or two particular skills.
- **Broad technology deployment options.** A wide variety of options can be used to play the games (traditional and mobile devices), both now and in the future.
- **Standards-aware.** The games can be developed to encompass learning objectives from standardized bodies of knowledge and certifications, using categories from a learning taxonomy (e.g., knowledge, attitude, skills). The content of the games and the student performance can be used to support accreditation efforts.
- **Semi-automated Game Development.** Given the need to rapidly and cost-effectively deploy new and modified games, a semi-automated, intelligent game development approach to broadly support instructors is needed to help script games. Re-usable assets (domain specific and domain independent) are needed such as quiz templates, quiz questions, answers, feedback.
- **Automated assessment and adaptation.** An unobtrusive means to collect and analyze game play data for an individual player’s assessment is needed; the results can be used to adapt the game for each player. To make it applicable to a wide variety of games (topics, education environments) the approach should be configurable.
- **Autonomous game play.** To keep games interesting for the player, a game engine with autonomous behavior is needed so the game is not exactly the same each time. Player profiles would also help make the game more interesting, by dynamically selecting and presenting a version of a question.
- **Faculty development.** Game-based curricula may be new for faculty, so the solution needs to specifically address how to help them develop these skills. For example, faculty will need to know how to ensure a game or collection of games covers a required set of learning objectives at a desired learning level.
- **Interdisciplinary stakeholders.** An interdisciplinary team of researchers (education, computer-science, game engineering), community (school boards), and industry partners is needed.

The SimSYS Development Platform for Serious Educational Games

Here, we present an overview of the SimSYS meta-model and the architecture. The meta-model provides the foundation for the project; the architecture realizes the technical goals presented above.

**SimSYS Meta-Model**

A meta-model facilitates the development of high-quality, engaging, educational games because it explicitly ties knowledge requirements, transferable skills and course outcomes to game production. Our proposed meta-model (Figure 1) serves several purposes. First, it provides a structure upon which similar categories of game-play components may be designed across a greater variety of games, providing an infinite combination of playing experiences while maintaining consistent pedagogical standards. Second, it facilitates the creation of games for faculty and game designers, as they would only need to toggle particular elements of game components that best suit the desired progress towards course learning.
objectives. Third, the meta-model creates a consistent discourse for serious games in higher education that may be applied across accreditation jurisdictions.

Key features of our meta-model are the modularization of domain specific bodies of knowledge (BOK), a learning taxonomy (e.g., Bloom’s), and skill based challenges. This supports the wide adoption across curricula, as domain specific knowledge can be “plugged-in” across multiple disciplines (STEM, humanities,…). In addition, our model situates learning opportunities in a plotline wherein the student-player advances by succeeding against time, non-player adversaries, and their own best scores. Knowledge-based challenges framed by a learning taxonomy develop the transferable skills required by accreditation standards that also provide feedback to both the player and the faculty member. Situating assessment challenges in an immersive game environment makes them more engaging and imaginative than typical online tests or assignments.

**SimSYS Architecture**

The SimSYS development platform solution is being systematically engineered using established architectural style. This style consists of a repository (stores knowledge) with controlled access and a collection of knowledge sources that directly interact with the repository (clients of the repository). Here, the repository is organized as a collection of domain dependent and domain independent sub-repositories. The domain dependent sub-repository stores game models (scripts), game play data, and re-usable game assets such as collections of domain specific Challenges (e.g., quiz questions/answers/feedback about software engineering, mathematics, physics, and so on) that are used in the games. The challenge content also captures relationships to Body of Knowledge standards (e.g., SWEBOK), Taxonomy of Learning standards (e.g., Bloom’s) and the level of difficulty (defined by educators). Re-usable domain independent game assets include the SimSYS specification templates, sound effects, graphic images; these are stored in a separate sub-repository. This organization has been adopted to support the rapid evolution or inclusion of new domains; we recognize there may be redundant storage of assets in domains that increases the storage overhead of this approach. When multiple domains have been prototyped, we plan to investigate the overhead cost and alternative optimizations.

The knowledge sources for the platform are modules that interact indirectly via changes to the repository. The modules include Game Generation, Player Assessment, Game Adaptation, and a Game Play Engine. These modules embody knowledge of related standards, including body of knowledge,
accreditation, and certification; the stakeholder interacting with a module can work with the content in the repository from a particular view. Each module is going to be realized in a prototype tool.

**Game Play Engine.** This module reads in the game script (XML); the player interacts with this module to play a game. A game is organized much like a play: a Game has one or more Acts; an Act has one or more Scenes; a Scene has one or more Screens; a Screen has zero or more Challenges. Traditional game elements are supported in this module, including the Characters, Context, and Mechanics. To provide a more interesting game the game play engine uses an agent-oriented approach, which makes the non-player characters more autonomous. The intent is that a non-player character can behave differently from game to game. The Game Play Engine is being developed using a test driven approach, in which a collection of test games have been specified to systematically develop and extend the architecture, design, and implementation of the engine. Each test game is described using a preliminary storyboard, then systematically refined into a collection of tabular templates and ultimately a game specification in XML. The XML game specification is varied to provide a rich collection of input test cases for the engine. The architecture for the Game Play Engine is based on an MVC style (MSDN, active mode); the three components are designed as concurrent, interacting state machines. Prototyping the Game Play Engine is an on-going effort – the research plan for summer 2013 includes refining the Game Play Engine to support 5 test games.

**Player Assessment and Adaptation.** These modules provide an unobtrusive means to collect game play data for player assessment and subsequently analyze it to tailor the game for an individual player. The approach is configurable with respect to the data collected and analyzed, to make it applicable to a wide variety of games. The data collected may include the number of correct answers, incorrect answers, length of time to answer a question, and number of times the player changes their answer. The data are collected as the game is played and stored in the repository for subsequent analysis; summary reports are automatically generated for the instructor. The analysis determines if the game is too easy, too hard, or at a good level for each individual player; data for collections of players are also analyzed. This module makes adaptation recommendations and chooses questions to present to the player at the next level of the game. These modules will use an aspect-oriented approach to collect the data and statistics to analyze the data. Ms. Bharathi Balasubramaniam recently completed her M.Sc. thesis on this topic: "Automated Assessment and Gameplay Adaptation in Serious Educational Games".

**Semi-Automated Intelligent Game Generation.** This module provides an intelligent approach to semi-automatically generate games for a domain. A wizard interface prompts the user to enter parameters for the
game they need such as domain, topics, depth, level of difficulty (target players), length, and plan for use in the curriculum. Users can work with the game script by viewing/editing it in a tabular template representation. Currently, game scripts are being developed manually using the (informally defined) tabular templates. This is very time consuming, and not amenable for broad adoption, in particular by educators not in a computer science or closely related field. Our proposed solution is component-based approach that composes a game out of game components: themes, locales, characters, lessons, challenges, and subjects. Currently, the Semi-Automated Intelligent Game Generation prototype supports the composition of specified game components. The research plan for summer 2013 is to extend the module to support the intelligent selection of components using an AI search algorithm.

**Preliminary Results**

SimSYS is being investigated from an interdisciplinary perspective (education, game research, and software). Our research first focused on the requirements and architecture specification for our game platform; the requirements and architecture for the Game Play Engine component; and developing a prototype Game Play Engine. Research is underway to explore the dynamic player and game assessment and adaptation of games and the automated game generation component of our platform. In addition, the development of SimSYS has coincided with ongoing research into the effective integration of tools like simulations and serious games into SE the curriculum. Finally, the presentation of SEIF-seeded SimSYS research at several cognate conferences has demonstrated a broader interest in the use of an agent-oriented simulation game in a wider range of disciplines. We plan to investigate how to develop serious games for other areas (e.g., dentistry, law, ethics), increasing the broader impact of this project.

While working on the Game Play Engine prototype with student teams, we discovered the need to define a tailored game engineering methodology to create a more predictable, consistent development environment from term to term. Using the Unified Process methodology, we have defined a tailored use case template to specify game play requirements that supports traceability to learning objectives (e.g., SE2004 knowledge areas, units, topics) and user engagement mechanisms (e.g., challenges, rewards, penalties, competition with an arch-enemy). We have been iteratively developing and applying the use case template to engineer the SimSYS Game Play Engine component and a collection of scripted games. The scripted games include a set of Test Games, which form the use case view of the Game Play Engine architecture, and the SimSYS Agile Software Development Process game. The templates are currently being formalized to support automated translation to Statecharts and XML game scripts. The Statechart model will be loaded and animated in IBM Rhapsody, to support their validation; the XML game scripts can be loaded into the Game Engine for testing.

Recent Refereed Publications include:

Additional Publications include:

**Research Team**

Dr. Kendra M.L. Cooper is an Associate Professor in the Computer Science department at The University of Texas at Dallas (UTD). Before joining UTD, Dr. Cooper worked in industry on large-scale, complex projects. Her research specialization is software and systems engineering with a focus on component based engineering and architecture; she has an extensive publication record. Dr. Cooper has taught a wide variety of undergraduate and graduate level courses in computer science and software engineering, supervised students' research at B.Sc., M.Sc. and Ph.D. levels. Dr. Cooper serves on numerous editorial boards and program committees for the SE community.

Dr. C. Shaun Longstreet is the Director of the Center for Teaching and Learning at Marquette University. He has twelve years of higher-education professional development experience, is an award winning educator with fifteen years of online teaching experience. He has presented extensively at peer-reviewed conferences on the subject of teaching with technology in higher-education. Dr. Longstreet also has been in charge of graduate student professional and teaching development in three faculty development positions at research-intensive state universities.

Research students (B.Sc., M.Sc., Ph.D.) are actively involved in the project, learning and applying advanced technical skills spanning software engineering, systems engineering, game research, and education topics. In addition, the research students will also be actively involved in supervising and mentoring small teams of independent study students, building leadership and management skills. Independent study students will be a diverse mix of B.Sc. and M.Sc. students. These students will participate in all aspects of the research and development of the game.

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