Information Sciences 264 (2014) 91–103

Contents lists available at ScienceDirect

Information Sciences

journal homepage: www.elsevier.com/locate/ins

An extensible micro-world for learning in the data networking professions

Dennis C. Frezzo [a], Kristen E. DiCerbo [b,*], John T. Behrens [b], Mark Chen [c]

[a] Cisco, United States
[b] Pearson, United States
[c] Independent Developer, United States

ARTICLE INFO

Article history:
Available online 30 October 2013

Keywords:
Serious game
Computer networking
Simulation

ABSTRACT

This paper describes the rationale, implementation logic, and user data related to a simulation-based serious game in the domain of computer networking. The resulting micro-world was created to provide rich and open user experiences that mimic important aspects of the real world relevant to technical knowledge, social understanding, and the application of skills in the networking domain. Simulation software called Packet Tracer provides a comprehensive micro-world authoring tool that allows the construction and use of network micro-worlds while a game layer called Aspire overlays Packet Tracer to simulate complex social interactions, requirements of problem formulation and solution, recovery from failure and other important skills needed for success in computer networking professions. These tools were designed from an ECD framework over a number of years and initial studies regarding their use are discussed.

1. Introduction

In this paper we discuss efforts to create digital environments to support individuals learning about computer networks and the practice of being computer network technicians, administrators, and engineers. Students and instructors are less concerned with what the learners know and can do in situations that are uniquely created for learning or assessment itself, but rather are concerned with the physical, affective, and cognitive reality of the world of work for computer networking professionals. We attempt to provide the opportunity for students to experience this world and collect data for feedback and decision support in the context of simulated micro-worlds that are part of a comprehensive instruction and education program.

The work described here takes place in the context of the Cisco Networking Academy (CNA). CNA is a global program in which beginning computer network engineering and Information and Communications Technology (ICT) literacy is taught through a blended program of face-to-face classroom instruction, hands-on lab experiences, an online curriculum, and online assessments [16,23]. Courses are delivered at high schools, 2- and 3-year community college and technical schools, 4-year colleges and universities, and non-profits. Since its inception in 1997, the Networking Academy has grown to reach a diverse population of about a million students each year in more than 165 countries.

A core motivation of this work is a focus on directly improving student learning by giving students and instructors increasingly detailed feedback regarding student knowledge, skills, and attributes in contexts that reflect those in which they will need to apply the information outside the classroom. As such, the systems we describe here are neither "assessment"

* Corresponding author. Address: Pearson Austin Operations Center, 400 Center Ridge Dr., Austin, TX 78753, United States. Tel.: +1 623 238 3511.
E-mail address: kristen.dicerbo@pearson.com (K.E. DiCerbo).

0020-0255/$ - see front matter
http://dx.doi.org/10.1016/j.ins.2013.10.024

systems nor "instructional" systems, but learning systems that break down the traditional barrier between instruction and assessment. As natural tasks become increasingly digital, the divide between the instructional experience and the assessment experience is unobtrusively closed [14]. As learners engage in what, for them, is a natural activity of game play, they work through challenges at a given instructional level, acquiring new knowledge and skills, while information about their performance is collected and analyzed to provide feedback within the game and to teachers outside. As such, the distinction between instruction and assessment fades away in the manner that occurs in the classroom of highly skilled teacher whose cycle of practice and observation are closely tied.

2. The state of the art

There have recently been two large, comprehensive meta-analyses recently completed examining the question of games and learning [42,10]. Both begin by looking at whether games were more effective than traditional classroom methods in terms of learning, and both found that they were, with similar effect size estimates of 0.29 [42] and 0.32 [10]. These results suggest that the recent interest in creating digital games for learning is justified.

However, the term "digital games" covers a wide array of software and implementations. The research question of most interest may now be, "what designs work for whom in under what conditions?" The meta-analyses above begin to point to questions and answers. Wouters et al. report that students learned more when: playing in groups than playing alone, games were supplemented with other instructional methods, and multiple training sessions were involved. In addition, the advantage of games over conventional instruction was largely seen when non-random assignment was used. This suggests that there may be factors that make particular students a good match for particular games. Although these factors remain to be specified, the studies with non-random assignment to games appeared to capitalize on them through student, teacher, or researcher selection.

Clark et al. also summarized studies comparing "enhanced" games with learner supports, enhanced interfaces, and other advanced designs to those using basic designs and found an overall effect size of .29 favoring the advanced designs. Unfortunately, there were too few studies of any given enhancement to determine which enhancements seem to work best under what conditions. Much of the current research on games for learning focuses on further developing complex enhancements and affordances. The following four topics are a representative (but not exhaustive) view of the work being done at the forefront of complex learning environments in an effort to further improve learning outcomes.

2.1. Adaptive/intelligent environments

Adaptive environments are those in which events that happen in the microworld depend upon the learners' actions and estimates of their knowledge, skills, and attributes. Environments can be adaptive in at least three ways: presentation (look and feel), problem sequencing, and problem-solving support [25]. Problem solving support typically involves providing hints and feedback based on player results. Work in the field of intelligent tutors that provide step-level feedback and require immediate error correction has shown that this method improves the outcomes of learners [17]. However, research with games suggests that players rarely ask for hints, and whether players attend to hints appears to be a complex interaction between when in game play it occurs, what type of hint it is, whether it is in response to a correct or incorrect move, and a players' general attitude toward hints [34].

To create a system in which the game adapts to the learner in ways that do not interrupt game play, the system must be able to assess levels of prior knowledge, learning progress, motivational states, and preferences. In the ELEKTRA game [25], a 3-D adventure game to teach eighth grade optics, the game engine uses players' actions to update the probability distributions of competence states. Based on the estimated probabilities, hints and supports are selected from a set of possible interventions. Further, if a player does something that is inconsistent with the estimated competencies (as often happens when players are exploring an open game environment), an assessment clarification, or activity designed to help provide assessment information, can be introduced. The game also contains competence activation, competence acquisition, and motivational adaptations to offer based on learner states. This use of probabilistic estimates of a variety of constructs and change to game states "on the fly" is representative of current work in this area.

2.2. Intelligent virtual agents/mentors

Related to the research on adaptive environments generally is research on intelligent virtual agents in games. Intelligent agents, or computer-generated characters that adaptively interact with the learner, often have the added challenge of being able to respond appropriately to natural language input. In order to build these agents, researchers have used complex statistical models to investigate dialogue structure and tutoring effectiveness in human pairs [8], while others have sought to construct computational models of socially normative conversational behavior [35].

Art Graesser and colleagues implemented a tutoring system, AutoTutor, in which agents hold conversations with learners in natural language [21]. After success as a tutor, the technology was expanded in the game Operation Aries, in which the human learner has "trialog" conversations with a student agent and a tutor agent in the process of detecting flaws in scientific studies (placed there by aliens attempting to take over the world). The agents respond to the natural language inputs of