Scaffolding in Adaptive Learning: Prototypes of Level Design and Hint Design

Muffie Wiebe Waterman, Cisco Systems, muwiebe@cisco.com
Dennis C. Frezzo, Cisco Systems, dfrezzo@cisco.com
Michael X. Wang, Vitapoly, Inc., michael@vitapoly.com

Abstract: We present early prototypes of an adaptive learning tool which show promise for scaffolding learner agency in developing domain skills and knowledge in Information Technology. Using a network simulator we have implemented adaptivity through levels and hinting in the contexts of an intelligent tutor and an educational game, applied either within a single activity or across a sequence of activities. Initial user testing with Instructors demonstrates feasibility and potential value of these tools for this global learning community.

Introduction

The future of work is changing rapidly and yet the pathways of learning into that future are not changing on pace. Learning Science holds that learners develop optimally when they are scaffolded with just the right level of support at just the right time (c.f, Davis & Miyake, 2018), but even when possible, this kind of support is often unevenly distributed. Adaptive learning tools may be a viable way to offer such support more equitably to students with differing goals, motivations and disciplinary identities; and with differing local resource availability. Current adaptive systems have been critiqued, however, for being narrowly scoped to provide next-action content-relevant support, versus broader learning skills (e.g., Saleh, et al., 2018). As schools K-16 increasingly adopt these technologies, the question of how adaptive systems can effectively scaffold aspects of learning such as agency and collaboration are of central concern to the Learning Sciences (Uttamchandani & Hmelo-Silver, 2019).

Taking a design-based research, rapid prototyping approach (c.f., Penuel et al., 2016), we are developing adaptive learning experiences in the domain of Information Technology (IT). Student agency is associated with greater learning outcomes, but questions remain as to how much agency is appropriate in a given context, and within game-based learning environments specifically, how to effectively scaffold agentic learning (Taub et al, 2020). Designing in a simulation-based learning environment, we are focused on student agency and networking domain understanding by exploring two dimensions of adaptivity: 1) hint design: when to offer hints, and how to structure domain-specific and affective components; and 2) level design: supporting both within-activity next step selection and across-activity next activity selection. In this paper we present an overview of two implementations: a simple intelligent tutoring system and a strategic simulation game's introductory levels. We report on what we have user tested to date and discuss next iterative work.

Context and learning tool

Through the Cisco Networking Academy, Cisco Systems has offered Information Technology (IT) curriculum freely licensed to institutions since 1997. Today the Networking Academy is a global learning platform, annually serving over 2 million students in 180 countries, through Instructor-led courses at over 12,000 institutions. Network simulation environment *Cisco Packet Tracer,* introduced in 2005, enables students to experiment with network behavior, building skills in network configuration, troubleshooting, and design which are contextualized in classroom work and hands-on labs with Instructor support. Previous research has shown *Packet Tracer* to afford an effective learning environment (Frezzo et al., 2010), and has established the substantive validity for the application of *Packet Tracer* as backend of an educational-simulation game called *Aspire* (DiCerbo et al., 2011).

Extensive assessment opportunities are embedded within *Packet Tracer*, structured as a 'grading tree' of all possible observables for a specified set of devices and conditions. Authors can create stand-alone graded

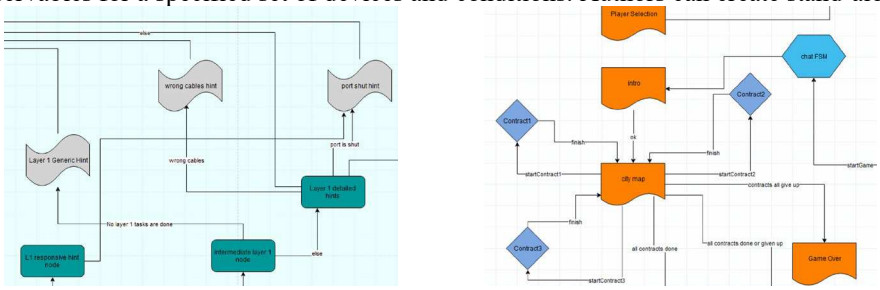

Figure 1. Snippets of a) *within*-pka and b) *across*-pka Finite State Machine levels in *Packet Tracer* editor mode.

activities (.pka files) using an automated wizard, incorporating scaffolds such as instructions, timers, checking progress against the grading tree, and network connectivity tests like 'ping.' We extend that learning environment by introducing adaptive scaffolds in support of students' increasing agency in problem solving networking activities. Scaffolding is achieved via next-level offerings and hinting prompts over a wide range of timescales (Figure 1), from within-pka file (steps within a single task) to across-pka files (across a sequence of activities).

Adaptive learning, level design, and hint design

Adaptive learning includes any algorithmic approach that takes student actions as evidence of student mastery and applies that evidence to the selection of appropriate next activity. Intelligent Tutoring Systems (ITS) are a robust area of application (e.g., VanLehn, 2006), yet research on adaptive hints in ITS has yielded conflicting findings (e.g., Aleven et al, 2016). Educational games are another active area, however research on systematic hint design in this context is more recent (e.g., Wauck & Fu, 2017). As such, effective level design and hint design for scaffolding learning in adaptive systems is still unfolding.

The current work uses the *Packet Tracer* interface and *Aspire* game environment to explore level design and hint design for student agency and content mastery. Levels are proxies for learner proficiency states, construed as steps within a single activity or sequences across activities, and are implemented as part of a Finite State Machine (FSM). Hints are based on learner actions and are provided on demand, rather than automatically. Following Aleven et al. (2016), hints are written to address the principles underlying the conceptual difficulty in completing the task. As the learner requests additional hints on the same task, they are scaffolded with increasing specificity: explaining first which principle applies to the situation, followed by what it means and how it applies. The bottom-out hint indicates what the learner should actually do to move forward with the problem-solving task.

Discussion and next steps

Early user testing has demonstrated feasibility and potential value of both the tutoring and educational game environments for this community of learners. Over 40 Networking Academy instructors have expressed strong desire to take these prototypes into their classrooms, reporting a variety of use cases they could immediately put into effect, from individual homework to collaborative learning in class. We will continue to iterate the prototypes, user testing with Instructors and Instructor trainers, and beginning user testing with Networking Academy students during 2020. Next work will examine 1) how level implementation and engagement, and hint use and efficacy may vary by learner persona, and 2) the efficacy of level design for understanding both next-step interventions within-activity, and across-activity persistence of student achievement. Given the global scale of NetAcad students, we hope to contribute to a broader understanding of effective design for adaptive learning scaffolds.

References

Aleven, V., Roll, I., McLaren, B. M., & Koedinger, K. R. (2016). Help helps, but only so much: Research on help-seeking in Intelligent Tutoring Systems. *International Journal of AI in Education, 26*(1), 205-223.

Davis, E. A., & Miyaki, N. (2018). *Scaffolding: A special issue of the Journal of the Learning Sciences*.

DiCerbo, K. D., Frezzo, D. C., & Deng, T. (2011). Substantive validity of a simulation-based game. *Research and Practice in Technology Enhanced Learning*, *6*(3), 161-185.

Frezzo, D. C., Behrens, J. T. & Mislevy, R. J. (2010). Design patterns for learning and assessment: Facilitating the introduction of a complex simulation-based learning environment into a community of instructors. *Journal of Science Education and Technology, 19*, 105-114. doi.org/10.1007/s10956-009-9192-0

Penuel, W. R., Cole, M., & O'Neill, D. K. (Eds.). (2016). Cultural-Historical Activity Theory approaches to Design-Based Research, [Special issue], *Journal of the Learning Sciences, 25*(4).

Saleh, A., Hmelo-Silver, C., Chen, Y., Shanahan, K., Rowe, J., & Lester, J. (2018). Scaffolding peer facilitation in computer-supported problem-based learning environments. In J. Kay and R. Luckin, (Eds.) *Rethinking Learning in the Digital Age: Making the Learning Sciences Count, 13th International Conference of the Learning Sciences, 3*, 1831-1834. London, UK: International Society of the Learning Sciences.

Taub, M., Sawyer, R., Smith, A., Rowe, J., Azevedo, R., & Lester, J. (2020). The agency effect: The impact of student agency on learning, emotions, and problem-solving behaviors in a game-based learning environment. *Computers & Education, 147*. doi.org/10.1016/j.compedu.2019.103781

Uttamchandani, S. & Hmelo-Silver, C. (2019). Structure for agency: Possibilities and challenges for Adaptive Collaborative Learning Support in educational equity projects. *CSCL Proceedings*, 895-6.

VanLehn, K. (2006). The behavior of tutoring systems. *International Journal of AI in Education, 16*(3), 227-265.

Wauck, H., & Fu, W-T. (2017). A data-driven multi-dimensional approach to hint design in video games. *Proceedings of the 22nd International Conference on Intelligent User Interfaces*, 137-147.