Interactive Pathway Design for Learning through Agent and Library Augmented Shared Knowledge Areas (ALASKA)

Eric Hamilton
US Air Force Academy

Abstract

This paper outlines a recently funded NSF-funded effort to integrate three learning technologies (perceptual agents; collaborative workspaces; and digital libraries). Each has emerged and matured over the past decade and each has presented compelling and oftentimes moving opportunities to alter educational practice and to render learning more effective. The project seeks a novel way to blend these technologies and to create and test a new model for human-machine partnership in learning settings. The innovation we are prototyping in this project creates an applet-rich shared space whereby a pedagogical agent at each learner's station functions as an instructional assistant to the teacher or professor and tutor to the student. The platform is intended to open a series of new -- and instructionally potent -- interactive pathways.

Introduction

Three different learning technologies and an intriguing opportunity to integrate them are at the heart of an educational research effort funded by the US National Science Foundation [1]. Each in its own right is at the forefront of a particular research domain. Each has emerged and matured over the past decade; and each has presented compelling and oftentimes moving opportunities to alter educational practice and to render learning more effective. This research project seeks a novel way to blend these technologies and to create and test a new model for human-machine partnership in learning settings.

The three learning technologies this project integrates are **perceptive animated agents** (an emerging class of intelligent, virtual tutors with life-like affective features); **shared collaborative workspaces** that enable users in a learning environment to remotely view and modify the displays of others; and **digital libraries** of small programs or applets that can illustrate, describe or provide visualizations of curriculum concepts. In each of these, the project relies on a steady pace of IT developments that have led to their most advanced current forms, and also on relevant human factors research. **The innovation we are prototyping in this project creates an applet-rich shared space whereby a perceptive animated agent at each learner's station functions as an instructional assistant to the teacher or professor and tutor to the student. The platform is intended to open a series of new -- and instructionally potent -- interactive pathways.**

With this platform, each student interacts with his or her personal agent in solving problems or acquiring new curricular concepts; the teacher can direct the agents; and all of the participants (teacher, students and agents) have immediate access to the curriculum-tailored library of applets that can provide clarifying visualizations, simulations, animations or fuller explanations of curriculum concepts. The agents communicate with each other and can collect and organize instructionally specific data across the class for the professor. The professor also has a perceptive agent in his or her space to organize data and to serve as an observer who can debrief with the instructor and with other agents in an adaptation of lesson study research [2].

We have given this platform the name "Agent and Applet Library Augmented Shared Knowledge Area," or ALASKA. ALASKA represents more than a system that aggregates features of agent, applet, and collaboration technologies. Our conjecture is that each of these three will exert a catalytic effect on the other two and **help to produce a new kind of distributed and heterogeneous network infrastructure for learning settings**: one that possesses not only technological power and sophistication but elegant and appealing symmetries consistent with research in learning and teaching.

This new project has three goals. They are to a) build the integrated ALASKA platform; b) refine, test and use a replicable process for embedding domain expertise in it; and c) test the network under classroom conditions in order to investigate research questions that cut across information technology, perceptive agents, learning and education. These goals are detailed following the scenario below. The scenario, taken from an introductory computer science class, may serve to illustrate some of the many shifts, both vivid and subtle, that the project attempts to stimulate and explore.

Scenario

Miriam was excited. Barely six weeks into the introductory but challenging CS105 computer science course she was teaching, she felt a strong rapport with her students. Sure, she wished that the distribution of student ability levels was not so great, but she had already discovered with increasing frequency that sometimes the most extraordinary performances came from seemingly ordinary students who became motivated and engaged.

Resources to help. She also felt so much more equipped for the class. A group of former CS105 students – now, hard to believe, in their senior year as CS majors – had helped develop a pool of explanatory applets to accompany the curriculum, and to find others from various sources that could also help. The upper level students were perfect for the job. They were close enough to their own experience as CS105 students to go right to the questions and issues that they and their peers really have, and at the same time they were learning themselves. They learned how to listen to the clients (both professors and students) and how to design, build and organize education objects. It was a great senior year practicum. Now in its second year the program was producing and polishing some very useful applets that had the twin virtues of being both reusable and modifiable to keep up with course changes. These seniors were more prepared to bring a balance of technical and user-oriented skills to the marketplace or graduate work.

Today's lesson. The lesson was a great topic. The class was in one of the course's programming modules. The students had learned in the previous days about nested loops and random number generators. This session was one of the payoff days when putting a few ideas together would produce some elegant mathematical results while creating some beautiful fractal imagery (who said computer science was not aesthetic?). The class discussion would be short and revolve around whether the random number generator could be used in an infinite loop to decide which of three functions might modify the x and y coordinates of a point to be plotted on a graphing canvas. One function cuts both the x and y coordinates in half. Another adds a large number to the x-coordinate but cuts the y coordinate in half, and the third adds a large number to the y coordinate while cutting the x coordinate in half. Each time the coordinates are modified and plotted, the random decision would repeat the point-plotting using the new coordinates. Miriam loved watching the students watch with puzzlement and pleasure as a fractal would unfold before them. Of course, she was not going to let on that anything unusual would be taking place. She led the discussion recapping the underlying concepts of random numbers and nested loops. She sent the programming exercise to the class and watched them start.

Some students get off to a quick start. Her first step was to do a run of thumbnail views of a group of twenty students – she could peer into a subset of their screens with sufficient resolution to see that several of them were off to the races. She touched the "encourage/correct so far" icon on her response palette and then icons for the students. Though they were in different parts of the room, most received a warm and friendly voice from their personal agents. Some simply received an encouraging gesture while a couple of agents stayed out of the way altogether. The agents had learned their students' preferences. They would later finish at different times. Each time they did, their respective agent would send a notification to the teacher's agent who posted a progress tally in the teacher's space. The agents also posed a set of probes for the students who completed, based on interests the agents had learned about their students. Two of the agents asked their students how the fractal would behave if its color parameters changed with each pixel using the same functions that modify the spatial coordinates. Other agents asked their students how it would behave with a different set of linear functions in the second and third functions. The agents were ready both to watch their students develop modifications to answer the follow-up probes and to retrieve a few examples themselves. In these particular cases, the agent would suggest the students write their own routine before they experimented with the applets. They were also ready to sketch a few pieces of information about the Collage Theorem on which the exercise was based. Miriam was confident that this group of her charges was in good shape.

Others are proceeding well. Miriam could see the screens of another group of students – it was not a trivial exercise, and they were tentative in their work but seemed to have the right idea. Some were sending questions that simply needed a one or two word answer that she would either shoot back or simply say to them across the room. Some were looking up a text explanation of nested loops and in a couple of cases the agent was working with the students. Even when she was working with Jason (below) she was able to answer quick questions that would have otherwise kept the students from proceeding.

Some are stuck. She knew from the thumbnails of the workspaces that several students were not able to start the exercise, and indeed she saw there were some who seemed confused. The classroom pattern called for the students to type or jot any question that needed clarifying and send it to the teacher if she was not immediately available to help them. Miriam's screen displayed several similar questions from around the class related to how to connect the random function to the decision about which of the three functions graphed the next circle. She realized she had not explained this clearly and decided whether to break the flow of the class by reexplaining this topic or whether to suggest an applet. The applets that the design team had built closely shadowed the CS105 curriculum and exercises, and there was indeed a nice visual routine that showed how random numbers could be used to drive decisions in a program. She sent a message to the students with the five questions. “Thanks for your question – I think that this applet might respond to your question. Take a look at it and let me know if it helps you get started. Your agent may suggest some other avenues but if this doesn’t help let me know right away.” A few minutes later, Miriam was able to thumbnail the screens of all these students and saw that they were all progressing. “Mike, Sarah, Tom, that explanation helped? The agents certainly could have done the follow-up, but it seemed easier just for Miriam to ask. The three, located around the classroom, nodded without taking their eyes off the screen.

Two aren’t able to start at all. Jason and Sue were a different story. They seemed lost. Sue had sent an alert that she did not really know where to begin, grateful for the anonymity of messaging. Jason didn’t bother with a message, but he knew that his professor could see from her station that he had not started. Miriam decided she would work directly with Jason after Sue’s agent sent a discreet query to the agents of the fastest moving students to see if any would volunteer their “student” to help Sue answer some questions to get started. The agents brokered a quick connection and the two students were able to work on the problem together in Sue’s workspace even though they weren’t sitting together and would not have any other easy way to match up without the agents. Miriam was able to help Jason, and Sue also received individualized help from another human, although now, six weeks into the course, almost everyone seemed comfortable and trusting of their personal agents.

Reflection. Miriam tried to decide whether her job was harder or easier with this environment. Both, she figured. The days of running around the class and trying to guess who might need her help the most were over. The days of guessing how many students were actually doing the problem-solving were over, as were the days of re-stating a lot of explanations she had given many times before. She was able to connect students where it made sense for one to help another, even if they were not sitting next to each other. But now that she saw a lot more of what was going on in the class, she had to keep track of a lot more information and spend her time on the more challenging work of understanding what her students were thinking. And the students were indeed thinking more. A large number of the students who were stuck or lost would have figured out something else to do with their time while she picked one or two of them to help– so would the four or five who only needed a few minutes to do the exercise. It seemed that the students were spending a much larger fraction of their class time doing real thinking and learning. There was a high performance expectation and high performance kind of resonance in the class. It was both easier and harder she decided, and certainly more complex. But more rewarding. She felt more challenged and knew that her students were functioning at a higher level throughout the class than they ever had before. Yes, more challenging and more rewarding.

She would share these reflections at the weekly CS105 debriefing. Her own agent functioned differently from the student agents. It had kept track of some vital information from the class, and would help her discussion. These debriefings were becoming one of the most important parts of her week.

Scenario Discussion

Miriam's instructional setting furnishes one vision for a ubiquitous e-learning experience. It involves the integration of a two-tiered set of perceptive agents into a distributed human learning environment, with critical and fast-moving information and knowledge transfers involving all of the network nodes and the applet libraries, and with agents brokering new student-to-student collaborations. These features enable new opportunities to transfer important research findings in cognition, learning and teaching to educational practice.

The scenario hopefully conveys a series of exciting potential new classroom dynamics that may redefine or shift traditionally assumed relationships or dyads in educational technology design. For example, research in pedagogical agents typically focuses on how the agents interact with students in one-on-one settings. In this scenario, they flexibly interact with students, teachers, and other agents. Digital library search and retrieval literature generally focuses on usability by students and teachers. In this scenario, applets are also called up by agents, sometimes at the direction of a supervising teacher.

Other dynamics also change. Students work together in a class only, in general, if they are spatially adjacent and only with teacher direction or intervention. **In this scenario, they work together from different locations under arrangements brokered invisibly on the network by their agents.** Some shifts are more subtle or tacit. Learners in connected classrooms can search for resources, but even among SCORM compliant and educationally sophisticated libraries, tools that map to a specific curriculum and to course specific questions may be difficult or impossible to locate and examine quickly to see if they "fit the moment's focus" [3]. When found, their granularity may be less appropriate or grounded than if they have been formulated by relative peers and professors who have taken or taught the course before. In this scenario, reflecting on how the design process produced her curriculum applet library, Miriam had good reason to believe that an appropriate applet was available to produce an instructional sequence and to thus free her to undertake important instructional tasks that were more challenging or complex than repeating an explanation that she had not given very clearly in the lecture. The steps the project is currently following will follow for building a computer science – capable set of agents comprise a testable, portable framework for use in other domains, including K12 and other college disciplines, especially mathematics.

Goal 1: Build the ALASKA Platform

But first, we must integrate the three technologies to produce the ALASKA platform to prepare it for testing within our initial learning content domain of computer science and problem-solving. To do so, this work capitalizes on and extends substantial investments by NSF and others in animated agent technologies, e.g., Cole, Vuuren et al [4], Graesser, Hu et al [5] and Bickmore and Cassell [6]; participatory design models for production of high quality and usable education objects, e.g., Roschelle, Kaput et al [7], Roschelle, DiGiano et al [8], DiGiano and Roschelle (2000) and, interestingly, collaborative Japanese lesson-studies [2]. The project leverages and extends a stable and successful shared workspace platform now in classroom use (SynchronEyes) produced and commercialized by this project's corporate partner (SMART Technologies).

Alaskan Elements: Shared Spaces, Applets and Agents

The three elements of agents, applets, and collaboration spaces are relatively far enough along research, development and production tracks to experiment with bringing them together in the integrated manner envisioned here. They are discusses briefly here, and in more detail elsewhere [1, 9].

For the purposes of this discussion, a shared workspace involves a software application – such as a programming editor or electronic sketchpad - that can be networked and shared by different users in a classroom in a "What You See Is What I See" or WYSIWIS manner and that also permits teacher-to-class screen broadcasting [10]. Whiteboarding over a network of classroom computers is a form of a shared electronic workspace. A user at one station in a whiteboard network can use text input, free-hand writing or annotation tools on a document, with markups or annotations appearing at the stations of other users. Whiteboarding is more commonly used in corporate conferencing software than in educational settings. Some non-commercial forms of shared workspaces have been developed by Hamilton [11] Greenberg, Hayne et al. [13], and Walters [14]. This project's interests lie with instructionally sophisticated WYSIWIS architectures whose interfaces feature authentic classroom rather than corporate training metaphors. This project will adapt a whiteboarding tool developed specifically for classroom use, SMART Technologies' SynchronEyes collaboration software. Now in Version 5, SynchronEyes presents a stable host for the applet and agent layering the project will require. The scenario references one of its critical features or capabilities of SynchronEyes, the ability to "thumbnail" or "hotbox" [11] the displays or workspaces of students in the classroom to obtain a "birds-eye" view at one time of multiple student workspace activities. SynchronEyes will host the integrated applet and agent features in a series of platform overlays to create what we refer to in the project title as a "shared knowledge area." It is currently part of a predecessor research effort that has demonstrated that rapid feedback cycles in classroom activities can scaffold and increase learner engagement in mathematics classrooms [15].

The scenario referenced a practicum in which upper level computer science students, collaborating with professors, developed a curriculum-fitting library of applets that the students, agents and professor could use. In this case, the students were also in a computer science course, but the model readily transfers to engineering education and will be used in an engineering education research grant on complex problem solving skill from NSF's Human and Social Dynamics Program. Applets are portable "mini-programs" that can produce text or video explanations, simulations, visualizations, animations, or graphical representations of course concepts. They are most commonly written in a variant of the Java programming language. Their interactivity is an important feature of their use with the perceptive agents. This model of rapid and customized object prototyping [16] has been developed by SRI in collaboration with Stanford University and the University of Colorado at Boulder [17] in the NSF-funded project called TRAILS -- Training and Resources for Assembling Interactive Learning Systems (http://www.trails-project.org).

Computer-based agents have evolved in many directions in the decades since Negroponte coined the term "electronic butler" (1970, cited in Baylor [18]). We adopt the description by Roesler and Hawkings (1994, cited in Baylor [18]), of an intelligent agent as an "independent computer program operating within a software environment such as operating systems, databases, or computer networks." Among important developments of recent years, significantly influenced by NSF investments, and in the still-broad subset of agents in *educational* settings, have been significant jumps in the conversational, facial and affect-simulating features of animated, intelligent agents [4, 19-21]. Agents are being created with more life-like, responsive, and credible features [22]. Baylor [18] reviews types of agents used in education in providing assistance or interventions for a learner. She is currently leading an engineering education effort investigating three roles that intelligent, animated agents can exert in learning settings: motivator; expert; or mentor who combines the motivator and expert roles [23]. Not surprisingly, she has found that the mentor-agent, combining the role of motivator and expert, was perceived by students as more engaging and useful than the other two agent forms, and produced greater learning effects. This is exactly the role we envision in the scenario at the beginning of the paper, with one significant extension: the "resources" that the agent brings to the relationship with the student includes connectivity: The agent has "friends" – other agents whose students can also provide assistance, a library of customized digital resources, and communication pathways to the teacher and his or her agent. And the interaction between a student and agent occurs over a more collaborative or open space, with the teacher able to observe or intervene.

Goals Two and Three: Embedding Domain Expertise and Platform Extensibility

The relatively complex network integration and engineering involved in Goal 1 (building the platform) provides critical infrastructure to support the basic research described in this paper. **Endowing the platform with usable domain expertise in the agents and applets is the second goal of the project.** It is inextricably intertwined and pursued in parallel with the first goal. The US Air Force Academy's Introduction to Computer Science (CS) course is taught in approximately twenty sections each semester. It features section blocks in areas such as computer and society, networking, programming and problem solving, and database development. **ALASKA will build domain expertise, including applet libraries, for the programming and problem solving block of this course**. We will subsequently seek applications in introductory engineering courses.

The programming and problem solving block should provide a rich introductory domain for ALASKA. Beyond this area, though, the **project seeks to build an extensible and portable platform for instruction in virtually any subject domain such as computer science or engineering**. A blueprint for domain portability proceeds through several phases in creating what we refer to as the "**domain topology**." We apply the term differently than other fields such as biochemistry or IT networking. The first of three layers of the topology consists of both the concept and cognitive maps associated with the domain – the content objectives and cognitive schemas and models related to those objectives. The second layer consists of the domain-specific semantic parsing of queries learners can pose and response paths that an intelligent agent can follow in guiding or tutoring a learner. That is, the second layer refers to the parsing, artificial intelligence, and other anthropomorphic capabilities or actions of the agent to guide the learner's cognitive map closer to the conceptual map of the domain. Adapting the construct of "**pedagogical content knowledge**" in teacher reform and research [24], this layer refers to the pedagogical content expertise of the agents [25]. The third layer consists of the architecturally independent library of domain-specific digital resources or applets that agents can retrieve and suggest or use. These independent resources can also be retrieved over the collaborative or shared space by the teacher or the student.

Goals Three and Four: Research Questions And Extended Research Agenda

An overarching research question this project addresses is whether ALASKA is feasible and useful as an operational tool for virtual and face-to-face classroom use. This large question aggregates a complex series of intermediate questions on both the software engineering side and content domain side. **Our stepwise approach to the platform integration, the development of a domain topology, and the consequent embedding of domain expertise into the platform (through the agents and applets) are being carefully documented as a case study in distributed and heterogeneous networking with multiple intelligent agents in learning settings.** A primary socio-technological perspective we will explore in this case study is thematic throughout the project and perhaps is best expressed succinctly in lay terms: **can networks that endow and engage *virtual humans* help propel richer, deeper and more meaningful interaction between *real humans* in contexts such as undergraduate engineering or computer science courses?** Our conjecture and vision is that they can – this is the vision expressed by Miriam's reflection on her classroom experience in our early scenario.

Once a working prototype is operational and undergoing the iterations of refinement that characterize platform development and design research, the team will explore a series of compelling research questions around five issues that appear below.

Research Issue 1: Learning Effects

A widely cited metastudy searching for empirical evidence on effects of animated agents on learning produced mixed findings [26]. A number of more recent studies, though, have found significant positive effects on learning [27] and motivation [28]. Studies by [5, 21]) suggest positive effects among undergraduates derived from dialogues with conversational agents in AutoTutor studies, but the role of the agent media itself (versus the dialogue process) is unclear. Johnson et al [29] suggest that it is premature to draw conclusions about the effectiveness of animated agents, because they are still in their infancy, and "…nearly every major facet of their communicative abilities needs considerable research" (p. 63). Our project hypothesizes that the importance and value of virtual tutors, measured in terms of learning speed, learning outcomes (e.g., retention, generalization) and quality of the learning experience, will increase as they become more and more like expert human tutors. We further expect to specify the nature of the agent benefit that is attributable to the dynamics that the ALASKA platform spurs in contrast to benefits derived from the tutor without the scaffolding resources of a collaborative space, applets, teacher, and other agents.

Research Issue 2: Extensibility and scalability

This project team will examine scalability as a researchable phenomenon from several vantages. **One vantage involves this project serving as a context for the scaling of the TRAILS approach.** We will test and report on the applicability of the rapid object development approach with college student co-designers that SRI has developed and its transferability to a domain outside of middle school mathematics. **A second scalability vantage is on the technical side**.

The network testing process entails capacity issues that are specific to single and distributed learning environments, respectively. The case study will separate these and report on network elasticity and information flow and load in the highly interactive sessions we are attempting to stimulate. **A third scalability vantage involves the framework we are testing for the formulation of a domain topology** – the breakdown of concept and cognitive maps, intelligent tutoring paths, and applets for a specific domain such as engineering mechanics or introductory design courses.

Research Issue 3: "Interactional bandwidth"

ALASKA will enable the professor to interact directly with a student's agent and direct the agent to furnish certain kinds of feedback and to direct or pose an applet to clarify or illustrate a concept. This involves both affective and cognitive communication. Recall that the agents, in their partial role as instructional assistants, are intended to pass affectively attuned communication on to students – the same kinds of messages that occur in normal person-to-person discourse**. We will test whether ALASKA will provide a significantly higher "interactional bandwidth" or density of affect-rich messages than can take place in a conventional classroom.** The teacher station will include a "response palette" that includes a repertoire of facially- and voice- nuanced responses s/he has available for agent inheritance or pass-through transmission to the student. In the ALASKA shared-workspace environment, the teacher can overview the thumbnails of everyone in the class simultaneously, collecting enough information to judge fairly accurately what group of students was starting on track, which needed some simple assistance, and which needed significantly more. She might press the icons, for example, for eight students scattered around the class; then, she selects from a palette a message – which consists both of words and expressions – that she deems appropriate for those eight (e.g., "Nice start! Let me know if you have any questions but you are definitely on the right track.) Pressing on a send button activates the agents at each of those eight stations. She can perform the same operation, say, for another group of five students but have the agents not only send a verbal message but suggest an applet (e.g., "When you are nesting multiple loops, make sure that you are incrementing the index values separately for each loop. Check out this quick animation if you think it might be helpful."). An expert teacher, with an ALASKA platform, might realistically be able to make such visual judgments and send a set of messages in a relatively short period of time – **perhaps one to two minutes, through which *thirteen* students receive agent-mediated, affect-rich, content-informed feedback from the teacher.** It involves only two sends over the network, but the messages are disbursed to thirteen different locations**. In theory, this represents a significantly higher number of informed, reasonably personalized and high quality feedback communications to those in the classroom than a conventional setting could allow**. It does so by allowing the teacher to scaffold the work of many agents at once, by originating and sending messages that the agents deliver or mediate. The messages are from both teacher and agents. We will specify and define the construct of interactional bandwidth; measure it with agent data capture and video analysis; and determine whether ALASKA-type platforms can elevate it.

Research Issue 4: Shifting task load over the network to increase human performance

Our vision for ALASKA is not the creation of a higher order IT-complexity for its own sake. **Rather, at least in part, our vision is that the prospect of a new IT configuration of team-teaching by humans and agent-assistants, with libraries available to both, can produce a more efficient and effective allocation of resources for high performance classroom flow, resulting in more engaging, exciting and satisfying learning experiences with better learning outcomes**. We will test whether applets, agents, and humans can function together in a classroom to relieve some of the performance load that has previously been expected of each, to free each to function more effectively in their core competencies (in the case of the teacher) or engineered features (in the case of the agents and applets). **More specifically, can ALASKA free the professor to undertake more cognitively or affectively complex processing to handle richer or more meaningful problems?** A similar question can be posed about enhancing agent performance, by having a supervising teacher present. For example, Bickmore and Cassel [30] have identified trust as a critical dimension in creating human-like relationships with animated agents. This work has explored the use of "small-talk" conversations between humans and agents to build trust. ALASKA is able to take a somewhat different tack, though, and bypass the engineering demands and overhead of endowing agents with the semantic capabilities required for life-life ice-breaking casual conversation with an animated agent. We will test the proposition that b**y endowing agents with the capacity to mediate teacher responses, they become extensions of the teacher, their anthropomorphic features become more trustworthy, and they become more engaged by learners and thus more productive as virtual tutors.**

Research Issue 5: Changing the professor's role

Philosophically, ALASKA bypasses the question of whether intelligent agents can (or should) replace instructors in the classroom or whether professorial enhancement is a more appropriate investment of scarce education research and reform resources. **It bypasses such questions in favor of a flexible environment that capitalizes on the professional knowledge, judgment and perception of the professor not only for directly working with students but also for marshaling and enhancing the sizable benefits of intelligent conversational agents.** The result we seek is an organic or naturalistic flexibility that respects teaching as a "complex and ill-structured domain" [31], with highly context-specific decision-making patterns that resist uniform or rigid responses to variable situations [32]. How instructors learn, grow, and change using this platform is a significant question. The vignette hints at some of these changes in Miriam's observation that her job was both easier and harder. She was relieved of a lot of repetitive instructional work that was replaced by tasks with higher cognitive demand and instructional significance. Her decision-making responsibilities changed.

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ERIC R. HAMILTON

Eric Hamilton is Visiting Professor at Hiroshima University and Director of Learning Technology, Institute for Information Technology Applications, US Air Force Academy. He received degrees from the Univ. of Chicago and a PhD in Mathematics Education from Northwestern. He is PI on NSF funded research on pedagogical agents and complex reasoning. He is a former NSF Program Director and Division Director.