Nomination of
Professor Ashok K. Goel for
Georgia Tech's Teaching and Learning Award

March 5, 2019

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This condensed CV focuses on Ashok Goel's Scholarship of Teaching and Learning

ASHOK K. GOEL
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I. PROFESSIONAL EDUCATION

M.S., Physics, The Ohio State University, 1980.

M.S., Computer and Information Science, The Ohio State University, 1982.

Ph.D., Computer and Information Science, The Ohio State University, 1989.

II. SELECTED ACADEMIC APPOINTMENTS

Assistant Professor of Computer Science, Georgia Tech, 1989-1995.

Associate Professor of Computer Science and Cognitive Science, Georgia Tech, 1995-2011.

Professor of Computer Science, Georgia Tech, 2011-present.

III. HONORS AND AWARDS IN TEACHING AND EDUCATION

Eli Lilly Teaching Fellowship, 1992-93.

Georgia Tech Sigma Xi Research Award for Outstanding Advisor of Undergraduate Research, 1992.

Georgia Tech College of Computing Outstanding Faculty Teaching Award, 1993.

Georgia Tech Center for Excellence in Teaching & Learning Junior Faculty Teaching Excellence Award, 1994.

Georgia Tech Order of Omega Faculty of Year Award, 1999.

Georgia Tech Class of 1940 Course Survey Teaching Effectiveness Award, 2014.

Georgia Tech College of Computing James C. Edenfield Special Faculty Award, 2015.

Georgia Tech Outstanding Use of Educational Technology Award, 2016.

Georgia Tech College of Computing Outstanding Faculty Teaching Award, 2017.

Selected for EAAI/AAAI Outstanding AI Educator Award, 2019.

IV. RESEARCH AND SCHOLARSHIP OF EDUCATION

A: Books

A. Madden, L. Margulieux, R. Kadell & A. Goel (editors), *Blended Learning in Practice: A Guide for Practitioners and Researchers,* MIT Press, forthcoming in March 2019.

A1: Book Chapters

J. Yen, M. Weissburg, M. Helms & A. Goel. Enhancing Innovation Through Biologically-Inspired Design. In *Biomimetics: Nature-Based Innovation*, Y. Bar-Cohen (editor), pp. 31-360, Taylor & Francis, 2011.

A. Goel, S. Rugaber, D. Joyner, S. Vattam, C. Hmelo-Silver, R. Jordan, S. Sinha, S. Honwad, & C. Eberbach. Learning Functional Models of Aquaria: The ACT project on Ecosystem Learning in Middle School Science. In *International Handbook on Meta-Cognition and Self-Regulated Learning,* R. Azevedo & V. Aleven (editors), pp. 545-560, Springer, 2013.

J. Yen, M. Helms, A. Goel, C. Tovey & M. Weissburg. Adaptive Evolution of Teaching Practices in Biologically Inspired Design. In *Biologically Inspired Design: Computational Methods and Tools*, A. Goel, D. McAdams & R. Stone (editors), Chapter 7, pp. 153-200, London: Springer-Verlag, 2014.

A. Goel. Preliminary Evidence for the Benefits of Online and Blended Learning. To appear in A. Madden, L. Margulieux, R, Kadell & A, Goel (editors), *Blended Learning in Practice: A Guide for Practitioners and Researchers,* MIT Press, forthcoming in March 2019.

A. Goel & L. Polepeddi. Jill Watson, A Virtual Teaching Assistant for Online Education. To appear in C. Dede, J. Richards & B. Saxberg (editors), *Education at Scale: Engineering Online Teaching and Learning*, NY: Routledge, forthcoming in 2019.

B. Journal Papers

S. Vattam, A. Goel, S. Rugaber, C. Hmelo-Silver, R. Jordan, S. Gray & S. Sinha. Understanding Complex Natural Systems by Articulating Structure-Behavior-Function Models. *Educational Technology & Society,* Special Issue on Creative Design, 14(1): 66-81, February 2011.

S. Sinha, S. Gray, C. E. Hmelo-Silver, R. Jordan, C. Eberbach, A. Goel, & S. Rugaber. Conceptual Representations for Transfer: A Case Study Looking Back and Looking Forward. *Frontline Learning Research,* 1(1), 2013.

A. Goel & D. Joyner. An Experiment in Teaching Artificial Intelligence Online. *International Journal for Scholarship of Technology-Enhanced Learning,* 1(1): 1-27, 2016.

B1: Edited Special Issues of Journals

C-S. Lee, J. Kolodner & A. Goel (editors). Scaffolding Creative Reasoning and Meaningful Learning, *Educational Technology and Society*, 14(1), February 2011.

B2: Formally Reviewed Magazine Articles

C. Hmelo-Silver, R. Jordan, S. Gray, M. Demeter, L. Liu, S. Vattam, S. Rugaber & A. Goel. Focusing on Function: Thinking Below the Surface of Complex Natural Systems. *Science Scope*, pp. 27-35, Summer 2008.

A. Goel & D. Joyner, Using AI to Teach AI. AI Magazine: Lessons from an Online AI Class. *AI Magazine*, 38(2): 48-59, Summer 2017.

C. Selected Conference Papers (Nominated for Best Paper Awards)

C. Eberbach, C, Hmelo-Silver, R. Jordan & A. Goel. Multiple Trajectories for Understanding Ecosystems. In *Procs. Tenth International Conference on Learning Sciences,* Sydney, Australia, July 2012.

D. (External) Research Grants Related to Education

1. Teaching Design Skills. Lilly Endowment Foundation. PI: Ashok Goel. Approximately $7,500. 1992-93.
2. Learning about Complex Systems in Middle School by Constructing Structure-Behavior-Function Models. NSF (Advanced Learning Technologies). PI: Ashok Goel. Co-PIs: Cindy Hmelo-Silver (Rutgers), Rebecca Jordan (Rutgers), and Spencer Rugaber. Approximately $635,000. 2006-09.
3. Systems and Cycles: Using Structure-Behavior-Function Thinking as a Conceptual Tool for Understanding Complex Natural Systems in Middle School Science. Department of Education (Institute of Educational Sciences). PI: Cindy Hmelo-Silver. Co-PIs: Ashok Goel, Rebecca Jordan & Spencer Rugaber. Amount: $1,725,000. 2009-12.
4. Biologically Inspired Design: A Novel Interdisciplinary Biology-Engineering Curriculum. NSF (TUES) PI: Jeanette Yen. Co-PIs: Ashok Goel, Wendy Newstetter, David Rosen & Marc Weissburg. Amount: $600,000. 2010-2012.
5. REU: Computational Tools for Enhancing Creativity in Biologically Inspired Design. NSF (CreativeIT) PI: Ashok Goel. Co-PIs: Bert Bras, Spencer Rugaber, Craig Tovey, Mark Weissburg, Jeannette Yen. Amount: $16,000. 2011,
6. Empowering Scientists and Students to Make Sense of Ecological Data through Model Construction, Evaluation and Revision. NSF BigData Program (South BigData Hub). PI: Ashok Goel; Co-PI: Jennifer Hammock. Approximately $1M, 2016-19.
7. PPSR, Empowering Scientists and Students to Make Sense of Ecological Data through Model Construction, Evaluation and Revision. NSF BigData Program. PI: Ashok Goel; Co-PI: Jennifer Hammock. Approximately $135K, 2017-19.
8. REU. Empowering Scientists and Students to Make Sense of Ecological Data through Model Construction, Evaluation and Revision. NSF BigData Program. PI: Ashok Goel; Co-PI: Jennifer Hammock. Approximately $32K, 2017-19.

V. PROFESSIONAL SERVICE AND LEADERSHIP IN EDUCATION

Member, Program Committee, Annual Meeting of the Cognitive Science Society, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018.

Member, Program Committee, International Conference on AI in Education, 2013, 2015, 2017, 2018.

Member, Program Committee, International Conference on Intelligent Tutoring Systems, 2014, 2016, 2018.

Sponsorship Chair, Annual Meeting of the Cognitive Science Society, 2018.

Co-Chair, Annual Meeting of the Cognitive Science Society, 2019.

Georgia Tech School of Interactive Computing
College of Computing

March 5, 2019

Center for Teaching and Learning Awards Selection Committee

Dear Colleagues,

It is with great pleasure that I nominate Professor Ashok K. Goel for Georgia Tech's Scholarship of Teaching and Learning Award. The Association for Advancement of Artificial Intelligence selected Professor Goel for the 2019 Outstanding AI Educator Award. (AAAI is the main professional AI society in the US and it typically gives just one such award each year.) AAAI has selected Professor Goel for the award because of "his sustained excellence in teaching, his innovation in using AI to teach AI, his scientific experimentation and scholarship to assess and improve AI pedagogy, and the many resources he shared with the community at large." Actually, this is also an excellent summary for Professor Goel's case for Georgia Tech's Scholarship of Teaching and Learning Award as well.

(1) **Teaching:** Professor Goel has been teaching at the college level since the mid-eighties, first as a graduate teaching assistant at The Ohio State University, and then as Georgia Tech faculty. He estimates that he has taught ~100 classes and >7,500 students during this time, with about half in face-to-face classes and the other half in online classes. Three characteristics of his teaching are that he (a) takes a design stance towards teaching of AI in which students learn through problem-based and project-based learning, (b) brings an interdisciplinary perspective to teaching, bringing insights from human cognition and learning to a range of AI topics from problem solving to creativity, and (c) documents the teaching and shares the educational resources with the community (https://github.com/dhconnelly/paip-python and https://www.udacity.com/course/knowledge-based-ai-cognitive-systems--ud409).

(2) **Quality:** As Georgia Tech faculty, in 1992 Professor Goel was selected as an Eli Lily Teaching Fellow, a national program for outstanding college professors. In 1993 and again in 2017, he won the College of Computing's Outstanding Teaching Award, one of only three faculty in the whole college to win the award more than once over the last quarter century. At the institute level, he won the Georgia Tech Outstanding Junior Faculty Teaching Award in 1994, the Georgia Tech Class of 1940 Course Survey Teaching Effectiveness Award in 2014, and the Georgia Tech Class of 1934 Outstanding Use of Innovative Educational Technology in 2017. As his Georgia Tech Class of 1940 Course Survey Teaching Effectiveness Award in 2014 indicates, student reviews of Professor Goel's teaching tend to be very positive, typically giving him a very high score of 4.8-4.9 for overall instruction effectiveness (out of a maximum of 5.0), and more than 1 standard deviation above the mean for Georgia Tech professors.

(3) **Innovation:** Professor Goel has long been a leader in innovation in education, especially in using AI to teach AI. In 2014, as part of the Georgia Tech Online Masters of Science in Computer Science program, he and (his then Ph.D. student) David Joyner developed an online course on Knowledge-Based AI. As part of this course, they developed ~150 exercises and ~100 cognitive tutors for the exercises, where each tutor provides formative assessment along with explanations to the students. While AI tutors have been around for quite a while, they rarely, if ever, have been embedded in videos at this scale. In addition, a little later, Professor Goel and his research group developed a virtual teaching assistant called

Jill Watson to automatically answer simple, routinely asked questions of the discussion forum of the class. The cognitive tutors and the virtual TA are now used in the residential KBAI classes as well. By now, ~3,500 online and residential students have used the cognitive tutors to learn KBAI and ~1,500 online and residential students have interacted with Jill Watson. In addition, Professor Goel repurposes AI projects in his research laboratory to promote authentic learning of AI in his classes. Thus, from 2010 through 2013, the projects in the residential KBAI class challenged the students to build AI agents that could pass the Raven's Progressive Matrices test of human intelligence. From 2014 through 2018, the online students in the KBAI class too had to address the same challenge: some of them did well enough to write a paper based on the projects.

(4) **Scholarship:** It is important to separate scholarship of education from the practice of teaching. Almost all AI academics engage in teaching, but very few invest in the scholarship of AI education; Professor Goel is an exception. As an example, his team has extensively evaluated the quality of video lessons in the online KBAI class. As another example, he explicitly specifies the learning goals, outcomes, and strategies of the KBAI class as well relate the assessments to the desired learning outcomes. They also provide early evaluations of the class, analyze what worked well and what did not, and abstract some principles for designing online AI classes more generally. In more recent work, his team has performed a longitudinal analysis of the evolution of the KBAI class from 2014 through 2016.

In sum, Professor Goel is not only an outstanding teacher but also an innovative leader in teaching as a leading scholar of education in AI. As a result of the sharing of his educational materials and the documentation of his teaching, the impact of his teaching goes far beyond his classes. I encourage you to give him the most serious consideration for Georgia Tech's Scholarship of Teaching and Learning Award.

Sincerely,

Ayanna Howard, Ph.D.
Professor and School Chair of Interactive Computing

Georgia Tech | Center for 21st Century Universities

March 5, 2018

Center for Teaching and Learning Award Selection Committee
Georgia Institute of Technology

Dear Colleagues,

I am delighted to recommend Professor Ashok K. Goel for the 2019 Scholarship of Teaching and Learning award. Professor Goel is clearly an outstanding teacher as evidenced by his many teaching awards, including the Georgia Tech College of Computing Outstanding Faculty Teaching Award (twice, which is very unusual), the Georgia Tech Outstanding Use of Educational Technology Awards, and the Georgia Tech Class of 1940 Course Survey Teaching Effectiveness Award. He is also a leader in developing innovative educational technologies, such as the virtual teaching assistant for online education named Jill Watson, which has received great attention in the media, including coverage by the Wall Street Journal, Business Insider, Wired, NPR, and PBS. Perhaps you may recall that he gave a talk to the Board of Regents in January 2017 on the Jill Watson project. In addition, he is a world-class scholar of education as indicated by many publications, including journal papers, book chapters, magazine articles and conference presentations. His work on artificial intelligence for education has had significant impact on the scholarship of educational technology, especially online education. In this letter, however, I want to talk about some aspects of his scholarship of education that are not as equally obvious from his condensed CV, but are especially relevant from the perspectives of Ernest Boyer's seminal work, *Scholarship Reconsidered: Priorities of the Professoriate.*

Georgia Tech Commission on Next in Education: I first met Ashok a couple of years back as part of the Georgia Tech Commission on Next in Education, that our Provost had appointed in late 2015 to envision Georgia Tech education in 2040. Ashok co-led the Commission's task forces on Future of Pedagogy and Future Learning Systems: the report of the former (http://www.provost.gatech.edu/education-commission/discovery-reports/future-pedagogy) was quite influential and is a testament to his scholarship. He also helped write the final report of the Commission (http://www.provost.gatech.edu/commission-creating-next-education), especially its sections on online education and the appendix on artificial intelligence. This an excellent example of what Boyer called the scholarship of education as well as the scholarship of integration.

Blended Learning in Practice: Much has been spoken and written about Ashok's online class on knowledge-based artificial intelligence and the use of virtual teaching assistants in the class. Less known is the fact that he has been using the same educational materials in support of blended learning in his residential class on knowledge-based artificial intelligence. In a quasiexperimental study Ashok found that the students in the residential class using blended learning and the students in the online class using the same educational materials performed about equally well on the same assessments. This is an example of Boyer's scholarship of education as well as scholarship of discovery and scholarship of application (or what he later called engagement). Now Ashok and a team of other practitioners of blended learning at Georgia Tech have put an edited volume together that will be published by MIT Press in early 2019.

NSF Scalable Advanced Learning Ecosystems Summit: On November 29-30, 2018, Ashok and I, together with a couple of other Georgia Tech colleagues, are organizing an NSF-sponsored workshop on Scalable Advanced Learning Ecosystems (or SALE). The goal of the workshop to bring together leading learning scientists from around the country to discuss how to scale effective education so that it is more accessible and affordable, and to write a report summarizing the workshop deliberations about the state of art as well, as emerging possibilities for the near future. Again, this is an example of Boyer's scholarship of education and scholarship of integration.

A Proposal for an NSF Science and Technology Center for Learning: I will make one final observation here. Ashok is leading a Georgia Tech-led effort towards a proposal for establishing an NSF Science and Technology Center for Learning. He has assembled a team that includes Harvard University as well as the Smithsonian Institution, and likely will engage the Gates Foundations and IBM. The proposal seeks to develop new models of learning based on our growing knowledge of neural, cognitive, social and cultural aspects of learning and enabled by new artificial intelligence technologies. This is an outstanding example of Boyer's four scholarships of discovery, education, integration, and engagement. As noted above these examples may not be readily apparent from Ashok's condensed CV).

In summary, Ashok is not only an outstanding teacher and an excellent scholar of learning and education, he also exemplifies Boyer's model of scholarship. He deserves the Scholarship of Teaching and Learning award and I urge you to consider him most seriously.

Sincerely,

Dr. Stephen W. Harmon
Associate Director, Center for 21st Century Universities
Associate Dean for Research, Professional Education
Professor, School of Industrial Design

The **Narrative of my Scholarship of Teaching and Learning**

Ashok Goel
Design & Intelligence Laboratory, Georgia Institute of Technology, Atlanta, Georgia, USA
goel@cc.gatech.edu

The Grand Challenge: Online education promises accessibility and affordability of learning to much larger sections of humanity than ever before. Thus, over the last decade, online education has grown rapidly. As one example, according to Class Central (https://www.class-central.com/), in 2017 more than eighty million learners around the world registered for a massively open online class (MOOC). In just one decade, more than a hundred million learners around the world have taken advantage of online education. However, student engagement in standard MOOCs typically is low and the student retention ratio often is less than 10%; a principle reason is lack of learning assistance. Further, there persist serious questions about the quality of learning in many MOOCs, again in part because of lack of learning assistance. As a result, while MOOCs continue to proliferate, their rate of growth appears to be declining. Thus, recently online education has developed new models of online learning such as Georgia Tech's Online Masters of Science in Computer Science program (OMSCS; http://www.omscs.gatech.edu). On the other hand, the use of online learning in flipped and blended classrooms in residential education is rapidly increasing. In fact, strategies and materials for online learning developed as part of the OMSCS program are now used extensively in residential classes as well. *Our grand challenge is to make online learning more effective and achievable for online education and to take online learning to new classes of residential and lifelong learners.*

High-Level Goals and Plans: Our research addresses two closely related goals at the intersection of human learning, AI, human-AI collaboration, and online education: (A) How can we use AI technology to make online education more effective and achievable? (B) How can we use AI technology to take new online learning to new classes of residential and lifelong learners?

We are presently developing a coordinated set of five AI technologies for assisting online learning: (1) *Virtual Cognitive Tutors* for learning domain concepts and skills in an online graduate class on AI (https://www.omscs.gatech.edu/cs-7637-knowledge-based-artificial-intelligence-cognitive-systems), and an online introductory class on computer programming (https://www.cc.gatech.edu/academics/degree-programs/bachelors/online-cs1301); (2) *Virtual Teaching Assistants* for answering questions and student introductions on the discussion forums of the graduate online AI class and the online introductory computing class; (3) A *Virtual Research Assistant* for learning through computational experimentation: The AI assistant provides biology students access to a large knowledgebase in support of ecological modeling and simulation; (4) A *Virtual Research Assistant* for learning through review of interdisciplinary literature: The AI assistant helps engineering students locate and understand biology articles relevant to design problems; and (5) A question-asking *Virtual Research Assistant* to help learners refine their business models for spawning startups: The AI assistant helps the learners assess their business models. While AI techniques 1 & 2 directly address goal A above, techniques 3, 4 and 5 directly address goal B.

AI Technologies: Below I briefly describe the above five technologies.

1. Virtual Cognitive Tutors: For the Georgia Tech CS 7637 online class on Knowledge-Based Artificial Intelligence (KBAI; Goel & Joyner 2016, 2017, 2018), we have developed a suite of ~100 virtual cognitive tutors called Nano that provides formative assessment and adaptive assistance to students. The cognitive tutors cover a wide variety of domain concepts and skills in the course, ranging from heuristic search to knowledge representation, from logic and planning to case-based and analogical reasoning. Each tutor is based on the AI technology of production rules. All tutors are embedded in 18 hours of class videos covering 26 core topics in KBAI. A student in the class encounters a tutor approximately every 8 minutes of video on average.

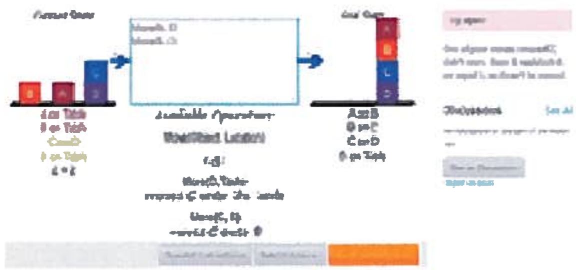

Figure 1: A screen shot of a cognitive tutor in the KBAI class. In this exercise, the tutor is helping a student learn about planning in blocks world by providing prompt and adaptive formative assessment.

Figure 1 shows some of the behaviors of a cognitive tutor in the KBAI class. The tutor operates by first assessing the readability of the student's input. The tutor next tests whether the readable input obeys the constraints of the problem. In Figure 2, for example, the student disobeyed a constraint of the problem. The tutor then explains the constraint to the student. Next,, if all constraints are obeyed, the tutor assesses whether the final state matches the goal state. If not, the tutor directs the student to the difference between her answer and the goal state. At every step of the process, the tutor contextualizes the feedback in terms of the target concept. The tutor is adaptive to the student's input and encourages mastery learning.

2. Virtual Teaching Assistants for Question Answering: When we first taught the Georgia Tech CS 7637 online KBAI class in Fall 2014, we found that the hundreds of students who took the class posted more than 10,000 messages on the online Piaza discussion forum for the class and thus overwheled the teaching staff. Thus, we have developed a virtual teaching assistant named Jill Watson that automatically answers routine, frequently asked questions posted on the online discussion forum (Goel & Polepeddi 2017, in press). Figure 2 illustrates an example of Jill Watson's question answering capability

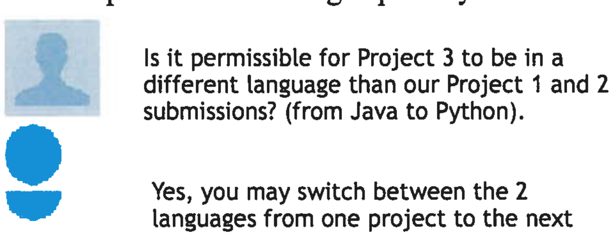

Figure 2: A student's question in the KBAI class and Jill Watson's answer to it.

We have so far developed several versions of Jill Watson with increasing capabilities.While the first version, Jill Watson 1, was based on IBM's Bluemix platform, the third version, Jill Watson 3, was based entirely on AI technology developed in our laboratory. Jill Watson 1 was essentially a digital library of question&answers from previous semesters organized into categories of questions. Given a new question, Jill classified the question into a category, retrieved an associated answer, and returned the answer if its confidence value was >97%. The confidence value was determined by the degree of match between the words in the question and the words in the answer.

3. *A Virtual Research Assistant for Computational Experimentation:* Residential students have access to physical laboratories, where they conduct experiments and participate in research, thus discovering new knowledge. Online students by definition do not have access to physical laboratories. Further, even residential students have only limited access to physical laboratories. Thus, we have developed a virtual research assistant called VERA for discovery learning through virtual experimentation (An et al. 2018): VERA helps biology students not only build conceptual models of ecological phenomena but also evaluate them through agent-based simulations: an AI compiler automatically translates the syntax of the conceptual model into the syntax of the simulation. Thus, VERA supports the whole cycle of model construction, evaluation, and revision.

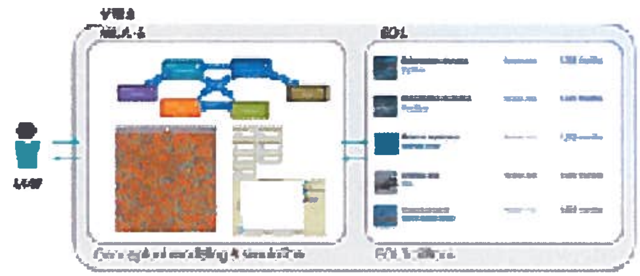

Figure 3: VERA includes MILA-S to enable users to create conceptual models about ecological phenomena and execute simulations. It uses the EOL TraitBank to scaffold the process of model construction and simulation.

As Figure 3 illustrates, VERA consists of MILA-S as the front end and EOL as the backend: MILA-S is our interactive environment for ecological experimentation through conceptual modeling and agent-based simulation (Joyner & Goel 2014), and EOL is Smithsonian Institution's database of biological taxa (www.eol.org). EOL's TraitBank supports a student in ecological modeling in two ways: it provides the ontology of conceptual relations as well as the parameters for setting up the simulations.

4. A Virtual Research Assistant for Literature Review: IBID is a virtual research assistant for discovery learning through literature review (Rugaber et al. 2016; Goel et al 2018): IBID helps engineering students locate and understand biology articles relevant to their design problems. Biomimicry is a design paradigm that uses nature as a source of practical, efficient and sustainable designs to stimulate the design of technological systems. However, most engineers are not experts at biology, and thus have difficulty finding and understanding biological systems relevant to their design problem. IBID uses AI techniques to search for natural language documents describing biological cases on the internet, and then construct an understanding of the retrieved biological cases for potential transfer to the design problem.

The IBID system operates in three modes. First, it extracts the functions, causal behaviors, and structural components of biological systems from biology articles, and annotates the articles with structural, behavioral and functional terms. Second, as Figure 4 depicts, given a design query, IBID helps locate biology articles relevant to the query based on the structural, behavioral and functional annotations. Third, IBID uses the structural, behavioral and functional annotations to help the student understand the functioning of the biological system. Figure 6 shows IBID's interface for locating biology articles relevant to a design query.

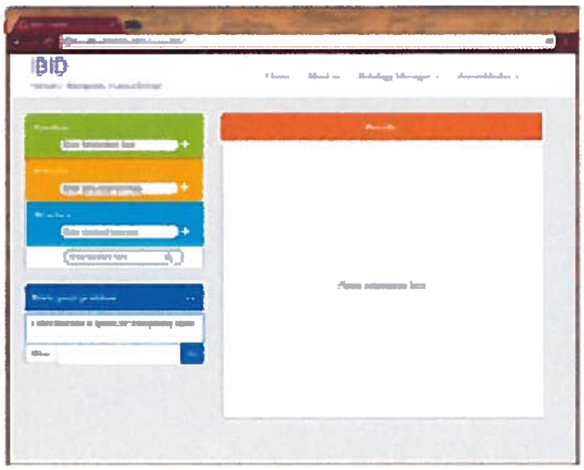

Figure 4: Search based on a design query (shown in the small pane on the bottom left) in IBID.

5. A Virtual Teaching Assistant for Formative Assessment: We are developing a virtual teaching assistant called Errol that helps learners revise their business models for spawning startups by asking them questions. The inspiration for Errol comes from the NSF I-Corps program that teaches academic scientists about customer discovery and business modeling. The teachers in the program typically are serial entrepreneurs who use the Socratic method of teaching: students in the program represent their business model on a Business Model Canvas (BMC) and the teachers ask probing questions intended to make the students rethink their value propositions, customer segments, and other elements of the business model.

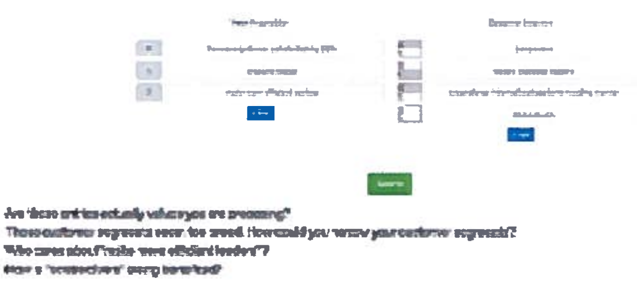

Figure 5: A screenshot of Errol. The learner's value propositions and customer segments are on the top left and top right respectively. Errol's questions to the learner are on the bottom left.

As Figure 5 illustrates, the current version of Errol focuses on the two most important panes of BMC: value propositions and customer segments. When a student enters value propositions and customer segments into BMC, Errol asks questions as a way of providing formative assessment.

Evidence of Impact of my Work on Teaching

Ashok Goel

The Challenge of Evaluating Impact: The evaluation of our AI technologies on student learning poses interesting challenges. Some research in education uses controlled experiments in laboratory settings. This has the benefit of isolating independent and dependent variables and studying causal relationships between them. Other research on AI in education focuses on semi-structured environments (such as middle school classrooms) that allow for control and experimental groups. This includes our own previous work on the ACT (Vattam et al. 2011; Goel et al. 2013), EMT (Eberbach et al. 2012; Joyner et al. 2011) and MILA (Joyner, Goel & Papin 2014; Joyner & Goel 2015) projects. In addition, we seek to evaluate the impact of our AI technology in open, largely unstructured, large-scale online learning: learning in the wild! In these settings it is not quite possible to conduct controlled experiments. To evaluate our AI technology in the wild, we build in part on our experience with the DANE project: DANE is a digital library of biological systems intended to support biomimetic design (Goel et al. 2010, 2012). In 2011, we shared DANE on the World Wide Web (http://dilab.cc.gatech.edu/dane/). It has received ~190,000 hits from ~9,000 unique visitors from the small biomimicry community and has been influential in the community.

We expect our AI technology to address both goals relating to our grand challenge described in the Narrative section: make learning in the online graduate KBAI class and the online undergraduate introductory programming class more effective and achievable (through Nano, Jill Watson, Noelle King described above), and take online learning to new classes of residential and lifelong learners through computational experimentation, literature review, and formative assessment for new classes of learners such as would-be entrepreneurs (Vera, IBID, and Errol respectively). In reference to the first goal, we evaluate if the virtual tutors and the virtual teaching assistants make online learning in the KBAI and introductory programming classes more engaging and result in better student retention and performance on the class assessments. In regards to the second goal, we evaluate if Vera supports citizen scientists engage in ecological modeling, if IBID helps designers seek biological inspiration, and if Errol assists would-be entrepreneurs develop more useful business models.

Evaluation of the Virtual Cognitive Tutors: We evaluate the virtual cognitive tutors using several metrics: (i) Number of virtual cognitive tutors, (ii) Number of online classes that have used them, (iii) Number of online students that have used them, (iv) Degree of adaptation and personalization in the tutors, (v) Student perceptions of the tutors, and (vi) Impact of the tutors on student learning. We estimate that more than three thousand (>3,000) online students have used the ~100 virtual tutors in the Georgia Tech online graduate KBAI class. We estimate further that more than two hundred residential students have used the same virtual tutors in the equivalent on-campus class.

Recall that the virtual cognitive tutors for the KBAI class are embedded in the video lessons (that are available for free from Udacity at https://www.udacity.com/course/knowledge-based-ai-cognitive-systems--ud409). We have conducted an analysis of student perceptions of the videos (Ou et al. 2016). Table 1 shows student responses of the online students to the KBAI class videos from a anonymous course survey in Spring 2017. These preliminary results appear to indicate that a large majority of the online students found the KBAI videos and the cognitive tutors embedded in them to be of high quality and helpful in learning KBAI concepts and skills.

Table 1: Number (and percentages) of online KBAI students in Spring 2017 who agreed with the four statements about KBAI videos

Statements about the video lessons with embedded tutors	*Number and Percentages of online students who agreed in the Spring 2017 offering of the KBAI class*
The lectures are informative and easy to understand.	74 (92.5)
The exercises provided during the lectures kept me engaged.	69 (87.3)
The feedback I received from the exercises enhanced my understanding of the lessons	60 (75.0)
Overall, the video lessons were valuable in helping me learn.	74 (92.5)

Evaluation of the Virtual Teaching Assistant for Question Answering: We evaluate the virtual teaching assistants (vTAs) for answering questions along several dimensions: (i) Number of virtual teaching assistants, (ii) Number of online classes that have used them, (iii) Number of online students that have used them, (iv) Range of coverage of questions and introductions, (v) Degree of accuracy in the answers and responses, (vi) Authenticity of the virtual teaching assistants compared to that of human teaching assistants. (vii) Student perceptions of the teaching assistants, (viii) Impact of the teaching assistants on students' self-efficacy and cognitive strategy; and (ix) Impact of the teaching assistants on student learning.

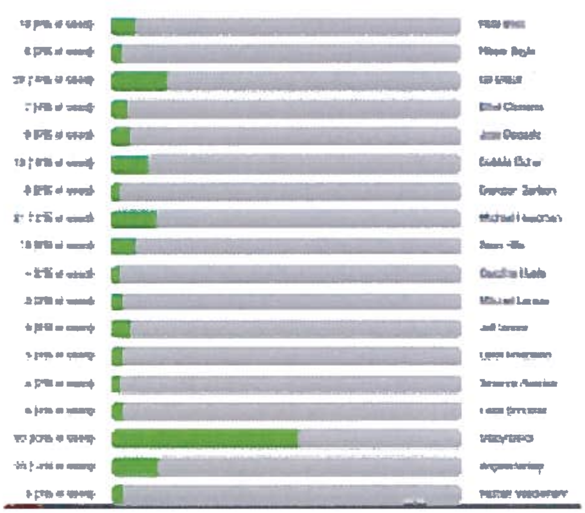

Figure 1: Percentages of students who thought various members of the teaching staff were AI agents in the online KBAI class.

At the end of Spring 2017, we found that the vTA in the KBAI class answered ~34% of logistical questions pertaining to the class assessments (assignments, projects, examinations) asked by online KBAI students on the class discussion forum (Goel & Polepeddi 2017). The accuracy rate was ~91%; most of the inaccuracies were minor. We also found that the vTA automatically generated responses to ~59% of student introductions.

In the online graduate KBAI class, all teaching assistants, human as well as virtual, operate under pseudonyms. At the start of a term, we tell the students of this fact, and at the end, we poll the students to determine if they can identify the vTAs among the teaching staff. Figure 1 shows the results of a poll of online KBAI students about the identity of the vTAs. While many students were able to correctly identify Ian Braun and Stacy Sisko as the vTAs, the authenticity of responses by the vTAs was high enough that not all students could correctly identify them among the teaching staff.

Programmatic Impact: We have performed several kinds of analyses for assessing the learning in the online graduate KBAI course. First, the completion ratio in the online KBAI class over various semesters is ~80% and thus comparable to the ratio in equivalent residential sections of the class.

Second, the student performance on the learning assessments in the online graduate KBAI course are comparable to that in the equivalent residential section, where the two sections share the same instructors, syllabus, structure, assessments and graders. Table 3 illustrates the comparison between the student grades in equivalent online and residential sections of one offering of the KBAI class; note that the grades on all assessment are almost the same.

Item	Max	Online (Mean)	Residential (Mean)	Residential – Online (Mean)
Assignment 1	40	34.15	33.59	-0.56
Assignment 2	40	34.09	33.24	-0.85
Assignment 3	40	35.19	34.78	-0.41
Project 1	100	81.37	81.01	-0.36
Project 2	100	70.67	71.11	0.44
Project 3	100	65.85	64.96	-0.89
Midterm	25	22.24	21.79	-0.45
Final Exam	25	22.19	22.40	0.21
Final Grade	100	81.06	79.93	-1.13

Table 3. Average grades on each assignment for the residential and online sections of the KBAI class in Fall 2016.

	Spring 2017	Fall 2017
Positive	0.229	0.21
Neutral	0.731	0.75
Negative	0.04	0.04

Table 4. Positive, neutral and negative valence for comments made in open-ended CIOS questions.

Third, we have performed an analysis of the anonymous Course and Instructor Survey (CIOS) that are conducted by Georgia Tech independent of the course instructors (Gonzales, Newman & Goel 2018). In particular, we analyzed the students' written comments for polarity of sentiments (Table 4). We also performed a more detailed analysis of the terms the online students used in relation to four specific components of the course (Table 5). We note the students view the online KBAI course much more positively (0.229 in Spring 2017) than negatively (0.04).

Noun	Positive	Negative	Frequency
course	0.196	0.032	154
project	0.147	0.041	124
assignments	0.121	0.019	94
lectures	0.221	0.017	88

Table 5. Commonly-used nouns, the positive and negative valences of the comments in which they occurred, and their frequency.

Fourth, Gonzales, Newman & Goel (2018) found that the online students in the KBAI class give high scores on standard metrics for measuring effectiveness of learning in a class such as the perceived intrinsic value of the course, use of effective cognitive strategies for learning, and perceived self-efficacy and learning assistance. In particular, in the Spring 2017 offering of the KBAI class we administered a variation of the Motivated Strategies for Learning Questionnaire (MSLQ) survey that uses a 7-point Likert scale. We adapted the MSLQ survey along the lines of standard self-efficacy scales. In fact, we conducted the same survey twice in the first and second halves of the KBAI class; the second survey was conducted after we revealed to the students the identity of the virtual teaching assistants. The preliminary results (Table 6) suggest that student's scores on all four areas of interest - cognitive strategy, self-efficacy, intrinsic value, and learning assistance - improved over the semester.

	Spring 2017	Fall 2017
Self-Efficacy P-value Mean	$p = 0.037$ BoT $\bar{x} = 5.55$ EoT $\bar{x} = 5.875$	$p = 0.028$ BoT $\bar{x} = 5.45$ EoT $\bar{x} = 5.73$
Cognitive Strategies P-value Mean	$p = 0.0398$ BoT $\bar{x} = 5.576$ EoT $\bar{x} = 5.73$	$p = 0.699$ BoT $\bar{x} = 5.597$ EoT $\bar{x} = 5.638$
Intrinsic Value P-value Mean	$p = 0.435$ BoT $\bar{x} = 5.736$ EoT $\bar{x} = 5.863$	$p = 0.0322$ BoT $\bar{x} = 5.964$ EoT $\bar{x} = 5.708$
Confidence in Teaching Support P-value Mean	$p = 0.241$ BoT $\bar{x} = 6.141$ EoT $\bar{x} = 6.306$	$p = 0.0750$ BoT $\bar{x} = 5.813$ EoT $\bar{x} = 6.025$
Total Participants	$n = 24$	$n = 73$

Table 6. Self-efficacy and other measures in the online KBAI class in Spring 2017 and Fall 2017 across all constructs. (BoT = Beginning of Term, EoT = End of Term).

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