ONE BOEING HR

ALWAYS PEOPLE FIRST

Building the Boeing 2030 Learning and Knowledge Infrastructure

Future Systems of Learning and Knowledge Development: Human Capital, Sociotechnical Systems and the flow of Information

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ASSOCIATE TECHNICAL FELLOW
THE BOEING COMPANY

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“The emergence of our contemporary networked society has brought disruptive changes, **reshaping the nature of relationships and interactions** and creating responsive, collaborative, and highly engaged culture” (Castells, 2000; Goodyear, 2014; Jones, 2015).

Changes in the skills and knowledge necessary for successful digital life and work flow are now **impacting organization cultural systems**. These changes promise rapid innovation for companies due to the need for a highly-educated “adaptive ”workforce, but to also give company’s new opportunities to **measure the flow-quality of information** including key competency and agility measures.

Employees in today’s workforce have thousands of options for re- and upskilling. In the U.S. alone, the more than 4,000 vastly different types of institutions of higher education offer more than 334,000 credentials. (Samson, 2018);

Degreed has over 100,000 content items, curation is not linked to relevance – quality, hence the relevant signals are lost in the noise of data.

Attention: the scarcest resource
Herbert Simon, prescient in this as in so many things, was one of the first people to highlight the attention scarcity problem:

“…in an information-rich world, the wealth of information means a dearth of something else: a scarcity of whatever it is that information consumes. ***What information consumes is rather obvious: it consumes the attention of its recipients. Hence a wealth of information creates a poverty of attention*** *and a need to allocate that attention efficiently among the overabundance of information sources that might consume it.”* (Simon, 1971)

From *Designing Organizations for an Information-Rich World*, in Martin Greenberger, Computers, Communication, and the Public Interest (1971 pp. 40–41).

1. Technology & Innovation

One of our goals for the next five to 10 years…is to basically get better than human level at all of the primary human senses: vision, hearing, language, general cognition. *Mark Zuckerberg, Facebook*

Human level AI will be passed in the mid 2020's, though many people won't accept that this has happened. After this point the risks associated with advanced AI will start to become practically important.
Shane Legg, Cofounder, DeepMind (now Google)

"Society's techno-social systems are becoming ever fasters and more computer-oriented…can generate a new behavioral regime as humans lose the ability to intervene in real time" *Johnson et al., 2013 (Nature)*

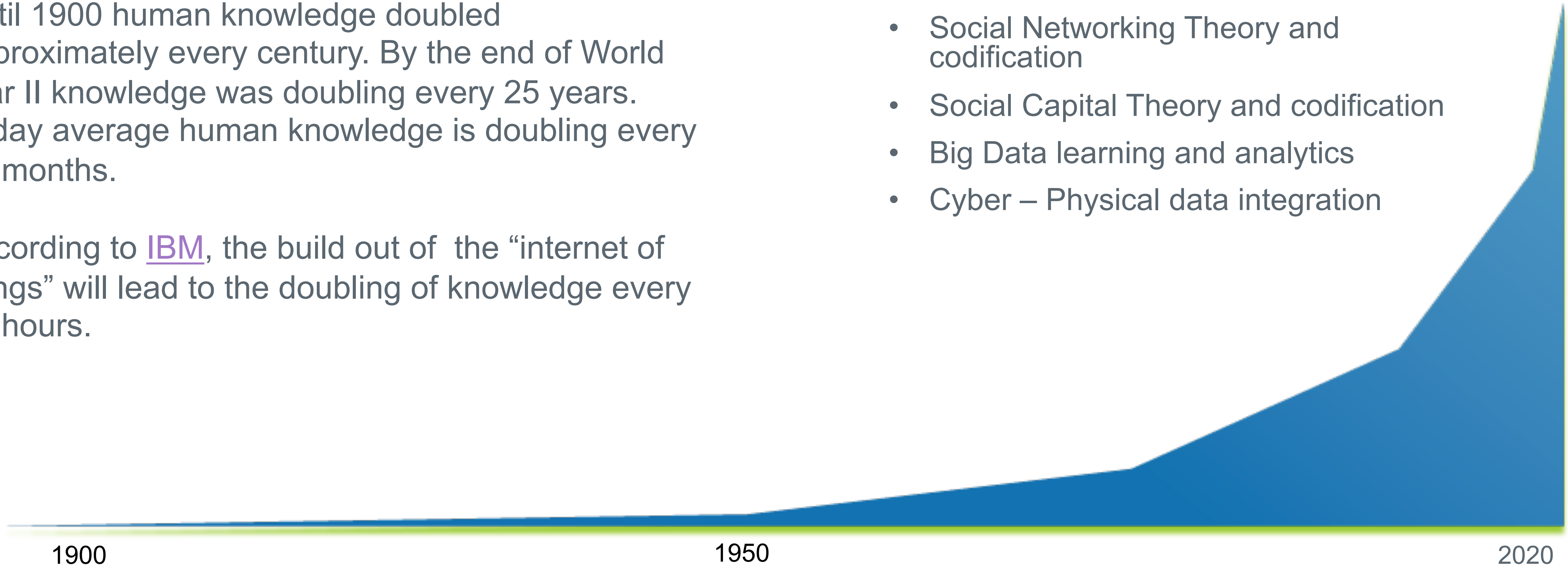
Information Doubling Curve:
Buckminster Fuller

Until 1900 human knowledge doubled approximately every century. By the end of World War II knowledge was doubling every 25 years. Today average human knowledge is doubling every 12 months.

According to IBM, the build out of the “internet of things” will lead to the doubling of knowledge every 12 hours.

Challenges:

- Knowledge elicitation and codification
- Social Networking Theory and codification
- Social Capital Theory and codification
- Big Data learning and analytics
- Cyber – Physical data integration



Until 1900 human knowledge doubled approximately every century. → By 1945 knowledge was doubling every 25 years. → Currently, on average human knowledge is doubling every 13 months. → IBM predicts the build out of the “internet of things” will lead to the doubling of knowledge every 12 hours.

Extended Intelligence”, whereby humans and machines craft a new model of collaboration

Top 10 skills

in 2020	in 2015
1. Complex Problem Solving	1. Complex Problem Solving
2. Critical Thinking	2. Coordinating with Others
3. Creativity	3. People Management
4. People Management	4. Critical Thinking
5. Coordinating with Others	5. Negotiation
6. Emotional Intelligence	6. Quality Control
7. Judgment and Decision Making	7. Service Orientation
8. Service Orientation	8. Judgment and Decision Making
9. Negotiation	9. Active Listening
10. Cognitive Flexibility	10. Creativity

Source: Top 10 skills Future of Jobs, World Economic Forum

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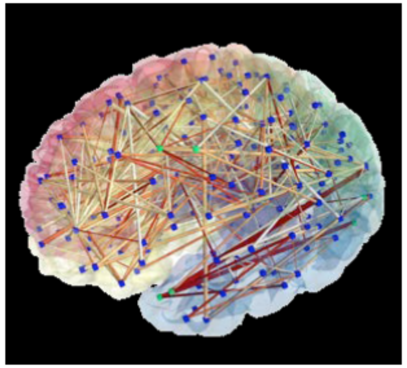
This change will require significant leadership from our public and private institutes. Martin Ford - author of Rise of the Robots - thinks we face mass unemployment and economic collapse unless we make radical changes.

- Top ten skills in 2020 will be: Complex Problem Solving, Critical thinking, Creativity, People Management, Collaboration – Cooperation and Coordinating with Others, Emotional Intelligence, Judgment and Decision Making, and Service Mindset
- Automation will displace 24.7 million jobs by 2027. This equates to a job loss of 17% between 2017 and 2027.
- New technology will also create 14.9 million new jobs in the next decade, with automation creating jobs equivalent to 10% of the workforce through 2027.
- While automation will lead to a net loss of 9.8 million US jobs by 2027, that’s nowhere near the 69 million many pundits have predicted.
- A survey done by the World Economic Forum’s Global Agenda Council on the Future of Software and Society shows people expect artificial intelligence machines to be part of a company’s board of directors by 2026.
- Emotional intelligence, and cognitive flexibility, which does not appear in the top 10 today, will become two of the top skills needed by all by 2020.
- Those working in sales and manufacturing will need new skills, such as technological literacy, critical thinking and cognitive flexibility, which don’t exist in the 2015 competencies.
- A recent report from the McKinsey Global Institute asserts that machine learning (a.k.a. data mining or predictive analytics) will be the driver of the next big wave of innovation
- Some suggest as AI progresses, few jobs will be safe. This includes teachers, lawyers, doctors and truck drivers.

Human and Artificial Cognition *(Continued)*

The National Academies report, Information Technology and the U.S. Workforce (2017), showing that over the coming 10 to 20 years, **technology will affect almost every occupation resulting in a high percentage of workers that need re-skilling.**

Moreover, machine learning and artificial intelligence threaten to not only eliminate a larger number of jobs than will be created through innovation (Brynjolfsson, Mitchell, & Rock, 2018; Manyika et al., 2017; Levy, 2017), but that **entire classes of professions will fall prey to machine learning and AI and many existing jobs will transform or change profoundly in the skills needed to perform them** (Gownder, et al., 2017; Witcher, Kodali, & Swerdlow, 2017)



Source: Bruce L. Horn
Intel Fellow & CTO, Intel®

"…what will happen when all people … become fluent with the deeper powers of expression that only the computer makes possible, and when these powers of expression bring forth a new way to discuss, think and argue important ideas. The real romance is out ahead and yet to come" –Alan Kay

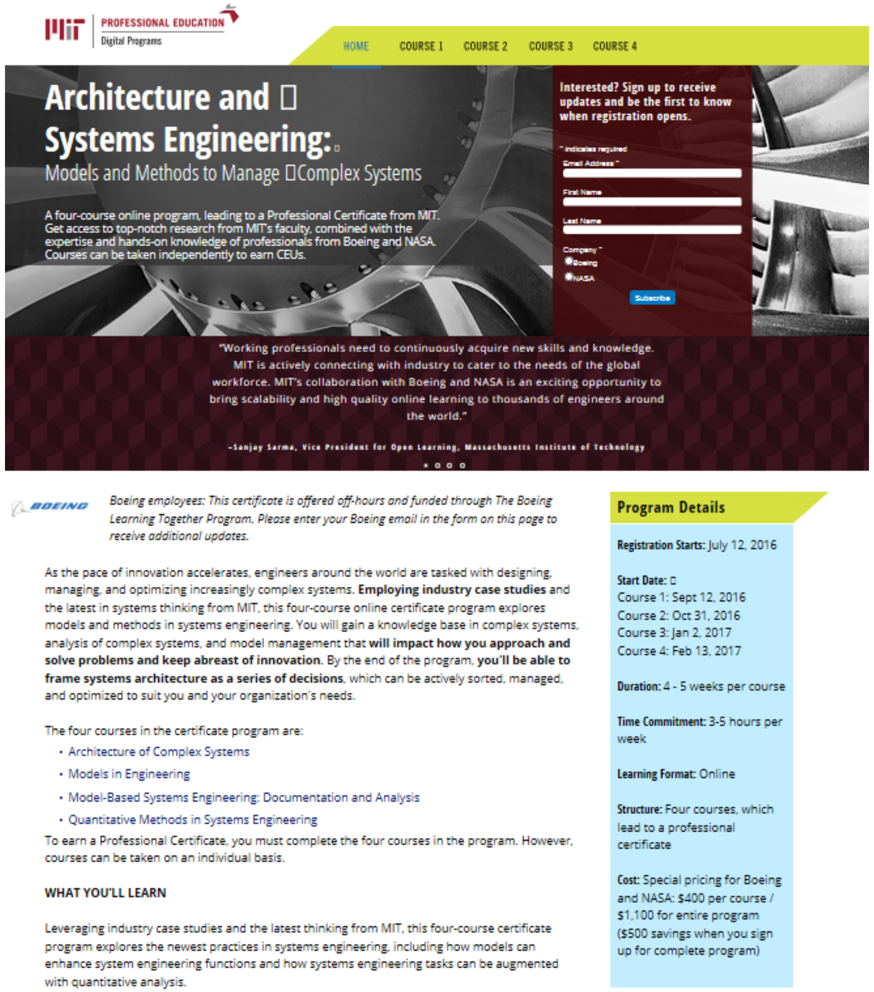
Cognitive Psychology
- Perception vs Cognition
- Case Studies of Existing Digital Assistants
- Increasing Emotional Intelligence

Approaches to Artificial Intelligence
- Beyond Five Tribes of Machine Learning
- Cognitive AI
- Complementary Learning & Real-World Systems
- Better Understanding of Common Sense Reasoning (Essence of Things)
- Data Selection for Reinforcement Learning

Natural Interfacing
- Natural Language Processing
- Gestures, Perception, Vision, Sound, etc.
- Mixed-initiative Interaction
- Augmented Reality to increase trust

6. Learning Sciences & Learning Analytics: Capture knowledge and advance personalized learning

MIT-Boeing Case Study:


PROFESSIONAL EDUCATION
Digital Programs

HOME COURSE 1 COURSE 2 COURSE 3 COURSE 4

Architecture and Systems Engineering:
Models and Methods to Manage Complex Systems

A four-course online program, leading to a Professional Certificate from MIT. Get access to top-notch research from MIT's faculty, combined with the expertise and hands-on knowledge of professionals from Boeing and NASA. Courses can be taken independently to earn CEUs.

Interested? Sign up to receive updates and be the first to know when registration opens.

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Company *
Boeing
NASA
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"Working professionals need to continuously acquire new skills and knowledge. MIT is actively connecting with industry to cater to the needs of the global workforce. MIT's collaboration with Boeing and NASA is an exciting opportunity to bring scalability and high quality online learning to thousands of engineers around the world."

–Sanjay Sarma, Vice President for Open Learning, Massachusetts Institute of Technology

BOEING

Boeing employees: This certificate is offered off-hours and funded through The Boeing Learning Together Program. Please enter your Boeing email in the form on this page to receive additional updates.

As the pace of innovation accelerates, engineers around the world are tasked with designing, managing, and optimizing increasingly complex systems. **Employing industry case studies** and the latest in systems thinking from MIT, this four-course online certificate program explores models and methods in systems engineering. You will gain a knowledge base in complex systems, analysis of complex systems, and model management that **will impact how you approach and solve problems and keep abreast of innovation.** By the end of the program, **you'll be able to frame systems architecture as a series of decisions**, which can be actively sorted, managed, and optimized to suit you and your organization's needs.

The four courses in the certificate program are:

- Architecture of Complex Systems
- Models in Engineering
- Model-Based Systems Engineering: Documentation and Analysis
- Quantitative Methods in Systems Engineering

To earn a Professional Certificate, you must complete the four courses in the program. However, courses can be taken on an individual basis.

WHAT YOU'LL LEARN

Leveraging industry case studies and the latest thinking from MIT, this four-course certificate program explores the newest practices in systems engineering, including how models can enhance system engineering functions and how systems engineering tasks can be augmented with quantitative analysis.

Program Details

Registration Starts: July 12, 2016

Start Date:
Course 1: Sept 12, 2016
Course 2: Oct 31, 2016
Course 3: Jan 2, 2017
Course 4: Feb 13, 2017

Duration: 4 - 5 weeks per course

Time Commitment: 3-5 hours per week

Learning Format: Online

Structure: Four courses, which lead to a professional certificate

Cost: Special pricing for Boeing and NASA: $400 per course / $1,100 for entire program ($500 savings when you sign up for complete program)

Our learning science research is intended to guide future work studying the association between contextual factors (i.e., demographic, classroom, and individual needs), student engagement (i.e., academic, industry, behavioral, cognitive, and affective engagement metrics) and learning outcomes (i.e., academic, social, and affective).


PLOS ONE

RESEARCH ARTICLE

Visualizing learner engagement, performance, and trajectories to evaluate and optimize online course design

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Check for updates

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Data Availability Statement: There are ethical and legal restrictions on sharing a de-identified version of the data set underlying this study, as the data contains sensitive information and are owned by MITx. the MIT Institutional Research group in the Office of the Provost coordinates the release of MITx data for research projects and will need to know details about the usage of data and purpose of the study in question. Contact ir@mit.edu with data requests. More information on requesting MITx data can be found at http://ir.mit.edu/mitx-data-request-checklist. We have submitted our

Abstract

Learning analytics and visualizations make it possible to examine and communicate learners' engagement, performance, and trajectories in online courses to evaluate and optimize course design for learners. This is particularly valuable for workforce training involving employees who need to acquire new knowledge in the most effective manner. This paper introduces a set of metrics and visualizations that aim to capture key dynamical aspects of learner engagement, performance, and course trajectories. The metrics are applied to identify prototypical behavior and learning pathways through and interactions with course content, activities, and assessments. The approach is exemplified and empirically validated using more than 30 million separate logged events that capture activities of 1,608 Boeing engineers taking the MITxPro Course, "Architecture of Complex Systems," delivered in Fall 2016. Visualization results show course structure and patterns of learner interactions with course material, activities, and assessments. Tree visualizations are used to represent course hierarchical structures and explicit sequence of content modules. Learner trajectory networks represent pathways and interactions of individual learners through course modules, revealing patterns of learner engagement, content access strategies, and performance. Results provide evidence for instructors and course designers for evaluating the usage and effectiveness of course materials and intervention strategies.

Introduction

In the information age, skills and knowledge required to perform professional jobs are changing rapidly. Proactive up-skilling and retraining of people are critical. Companies are spending billions of dollars each year to develop courses, train their existing workforce, and onboard new hires. Many companies resort to mass training; the majority being inefficient web based and costly instructor lead training with some companies innovating in teaching and learning analytics to increase return on investment (ROI) for the many diverse learning and training interventions [1].

PLOS ONE | https://doi.org/10.1371/journal.pone.0215964 May 6, 2019 1/19

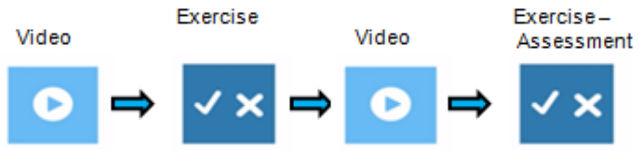
Results:

- First Run: 1,611 Boeing engineers registered and signed informed consent waiver.
- Of these, 1,565 engineers were active in the course generating nearly 31 million click event records while accessing videos, projects, and assessments.
- Some students generated over 100,000 separate events.
- Certificate completion rate of 84.1% that is much higher than achieved in a typical MOOC.

Learning analytics and visualizations make it possible to examine and communicate learners' engagement, performance, and trajectories in online courses to evaluate and optimize course design for learners. This is particularly valuable for workforce training involving employees who need to acquire new knowledge in the most effective manner.

5. Human Capital: Certificate Design Principles

We are leveraging formative – summative (pre-post) assessments, Item Response Theory, Social Network and Social Capital Theory to probe student understanding to determine "what is in the Black Box" of the learner's mind (Black & William, 1998).



Page Types

- Video
- Non-Video/Other
- Social
- Ungraded Assessment
- Graded Assessment
- Team Project
- Polls & Surveys

Course 1 Architecture: Module 1

5. Human Capital: Certificate Structure Assessments

Insights is edX's native analytics tool. It allows us to measure learner engagement in a number of ways:

Content Engagement

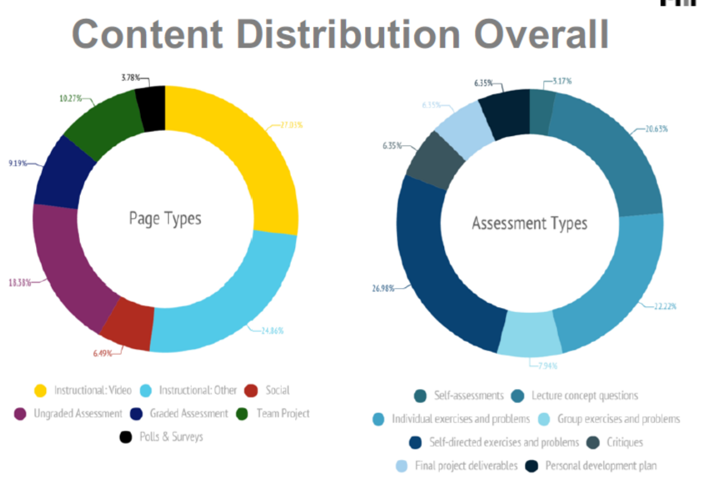
- Insights provides information on module and course completion, pages viewed, what videos students watched/didn't watch, and how much of the videos they watched

Activity Engagement

- Insights can tell us what activities students chose to do (for those that aren't required, ie the ungraded activities), how they did, and whether they revised their answers if their initial responses were incorrect

Social Engagement

- Information about discussion board activity, with specific breakdowns on activity by questions and topic areas
- Additionally, we would like to quantify social engagement in order to factor it into learners' final grade; however, this is not currently supported by edX's current grading tools and so we may need to revisit how and if we can include this in our course grade model



Self Assessments

- Description: At a few key points in the courses, learners gauge their personal estimate of what they've learned against the course learning objectives; serves as a powerful form of reflection as well as a roadmap of what they've learned
- Graded/Ungraded: Ungraded
- Format: edX short answers; surveys

Social Activities

- Description: Learners are required to think about their own personal interpretation of the content, such as a solution to a problem, an analogous example, or personal story, and share it with their peers; there is no right or wrong answer provided their submissions are aligned with the goals of the activity; learners are encouraged to participate in threaded discussions in response to the submissions of their peers
- Graded/Ungraded: Graded
- Format: edX Discussion Forum

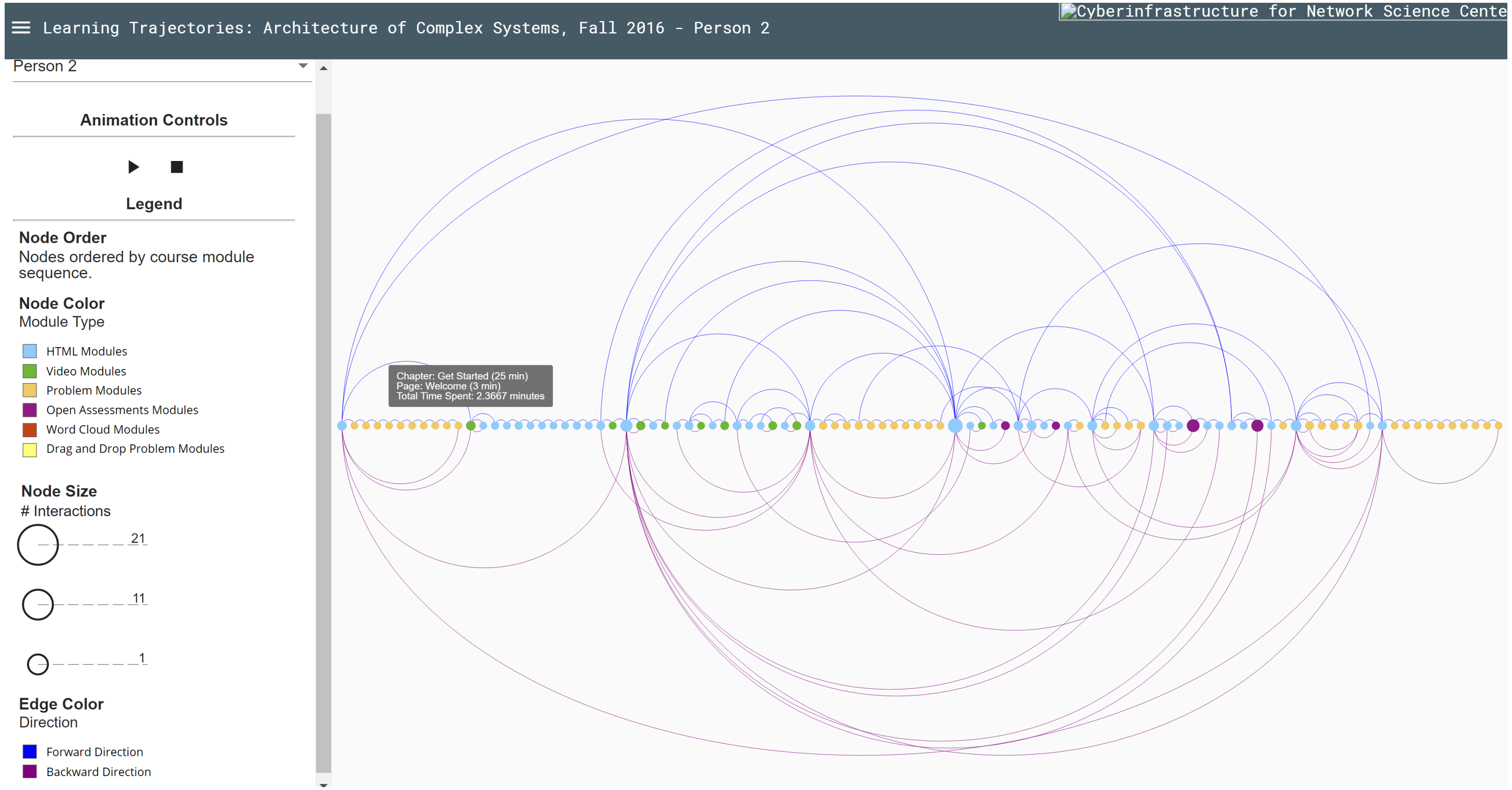
Graded Activities

- Description: Graded activities will conclude some sections of each module, as determined by the relative importance and/or complexity of the content; the graded activities will be scaffolded, though in most cases less tightly than the practice; this is where learners will demonstrate that they can apply a specific concept or behavior; some of these activities will also require learners to review and offer feedback, using a rubric, on their peers' work
- Graded/Ungraded: Graded
- Format: edX interactives; peer-to-peer activities

Project Work

- Description: The culmination of each module will be project work, a series of complex, authentic tasks in which learners synthesize what they've learned and apply it to a real-world situation; the project work for most learners will also require collaboration with other members of their project team (assigned by the system admin); projects will be submitted at the end of the course and graded by the course admins

5. Human Capital: Learner path overlaid on linear sequence of course modules



https://demo.cns.iu.edu/client/learning-trajectories/

Improving Return on Investment in Education: Measuring, Visualizing, and Optimizing Learner Trajectories, Michael C. Richey, Michael Ginda, Mark Cousino, Katy Börner

Information by Instructor

- Time estimates: Instructor provided course time estimates for a chapter module do not align with time estimates associated with pages of low-level edX blocks.
- Task Difficulty. Estimates for cognitive load (e.g., using Bloom's taxonomy typology) for each learning module based on test runs and taking into account learners' expertise.
- Sequence of Learning Modules. What is the instructor prescribed sequence of learning modules (for different learner cohorts)?
- Consumption-Production Matrix. What content is tested in which problems, exams?
- Success Metrics. Final grade may not be the best indicator of learning success.

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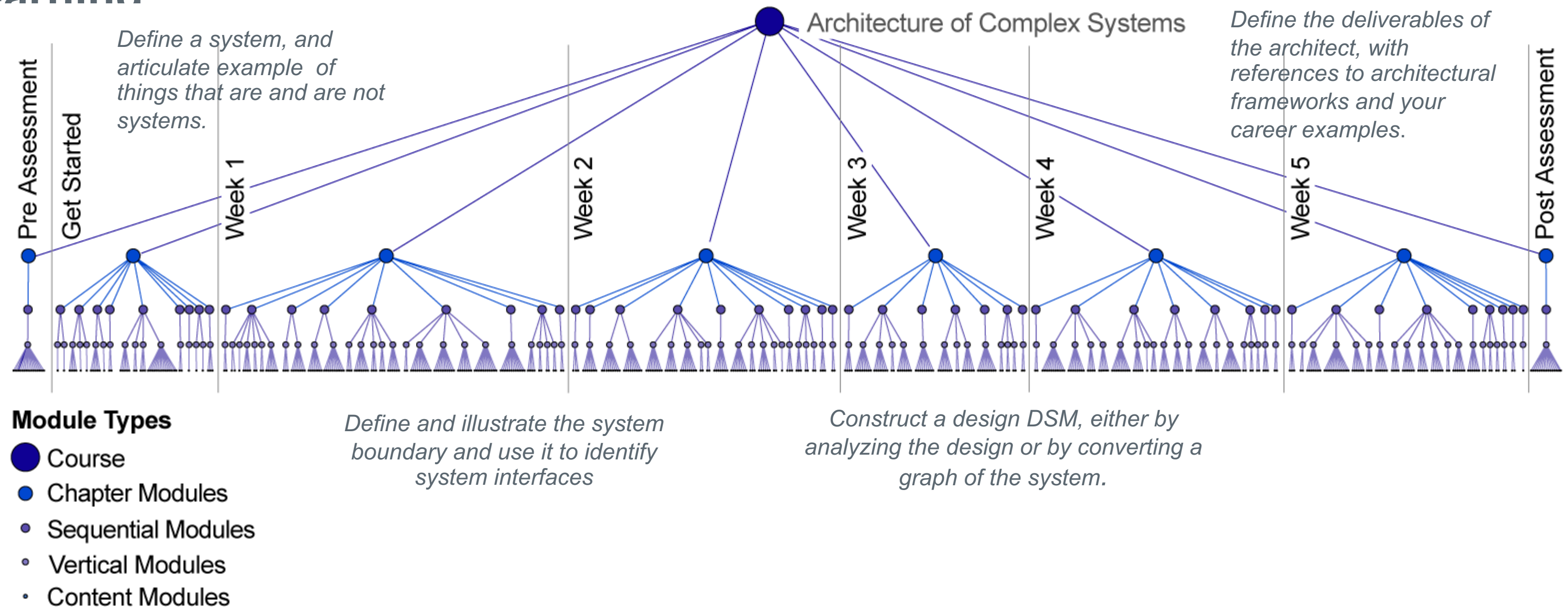
Learning Sciences & Learning Analytics: Capture knowledge and advance personalized learning



Course Structure Tree Diagram shows 5-level hierarchical structure of the *Architecture of Complex Systems* course.

Nodes are ordered based on the sequence of learning modules presented to learners in the course.

Insights: Course structure allows for analysis and visualizations at multiple levels of granularity, temporality. We can also see that courses share similar lengths in modules presented to students.

Results:

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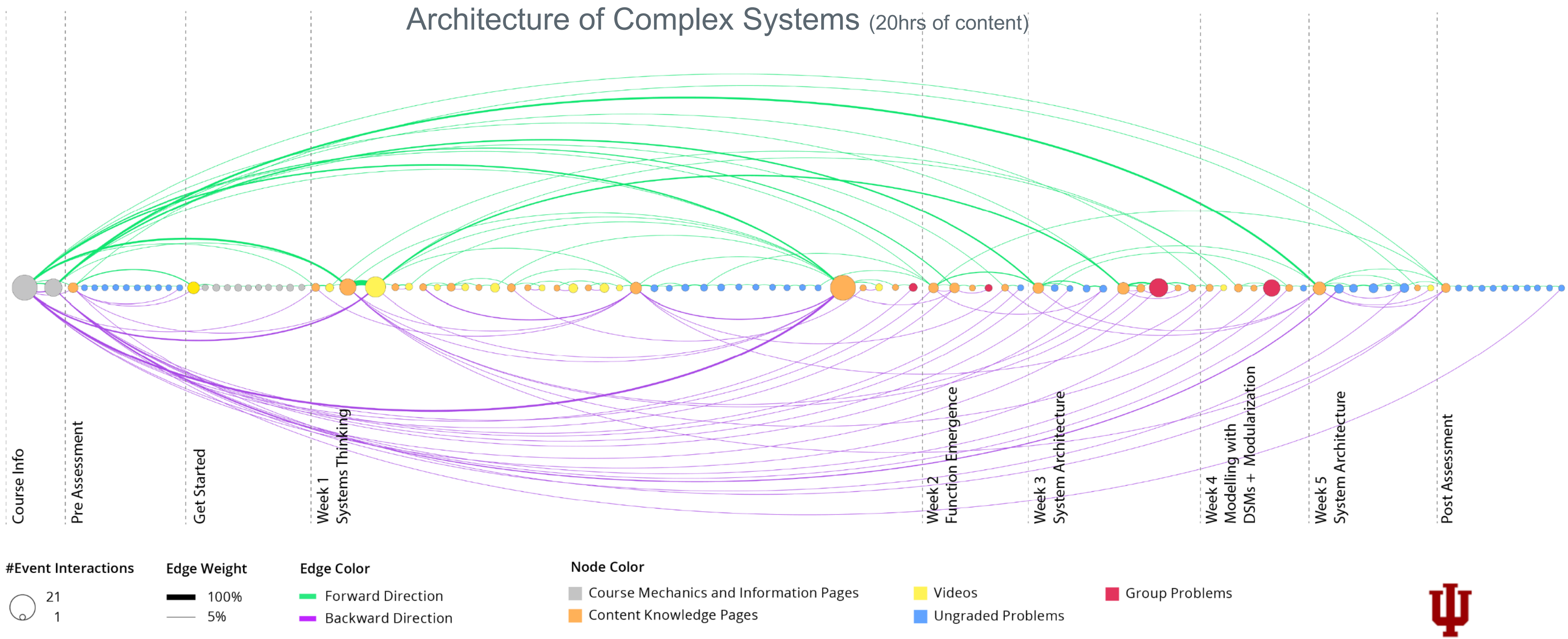
6. Learning Sciences & Learning Analytics: Capture knowledge and advance personalized learning



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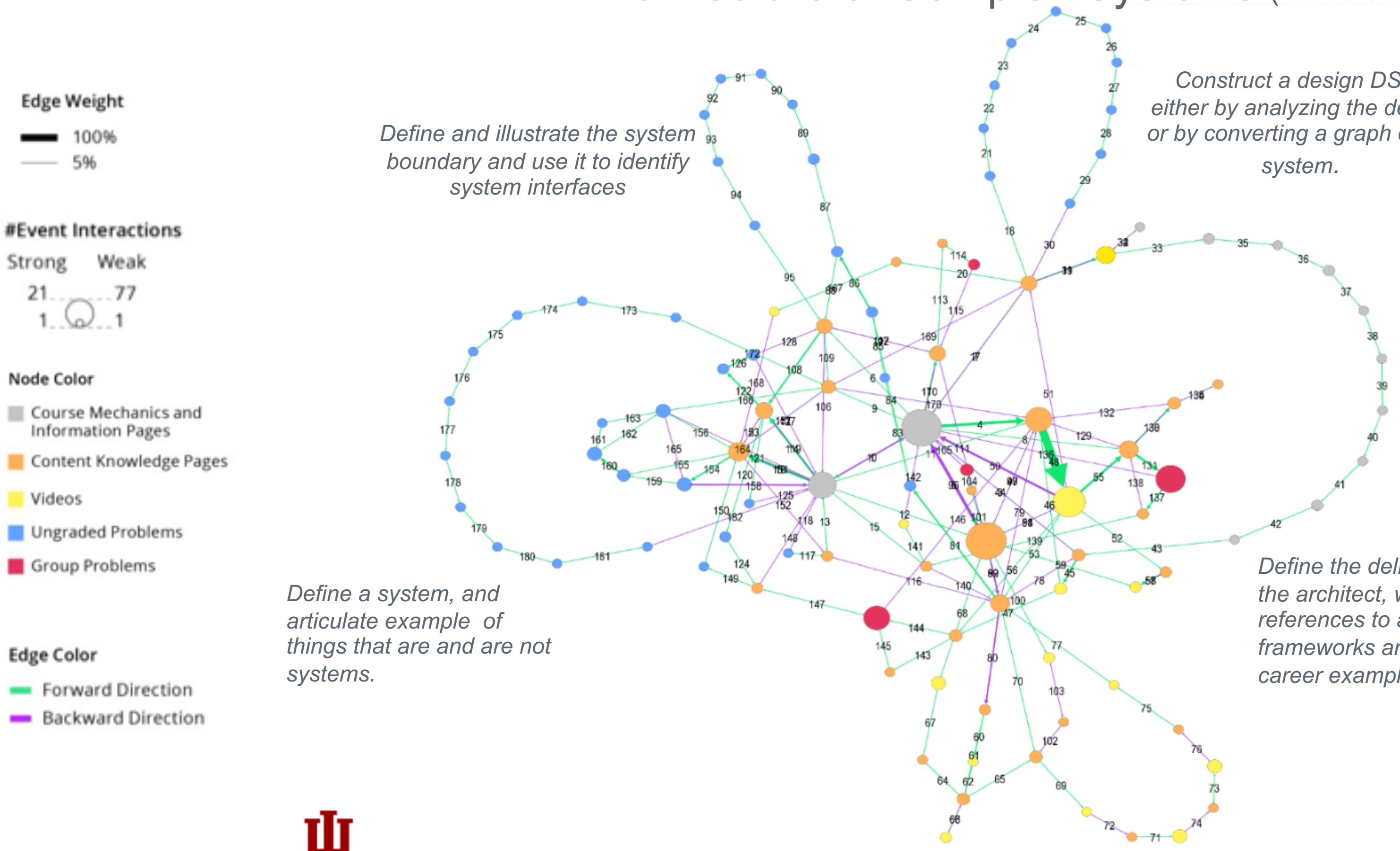
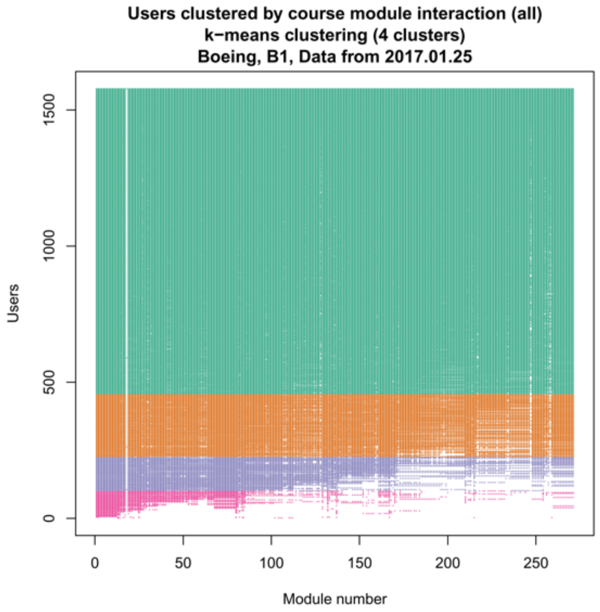
6. Learning Sciences & Learning Analytics: Capture knowledge and advance personalized learning

Architecture of Complex Systems (20hrs of content)





What are patterns of trajectories in professional engineers' usage of online course material?

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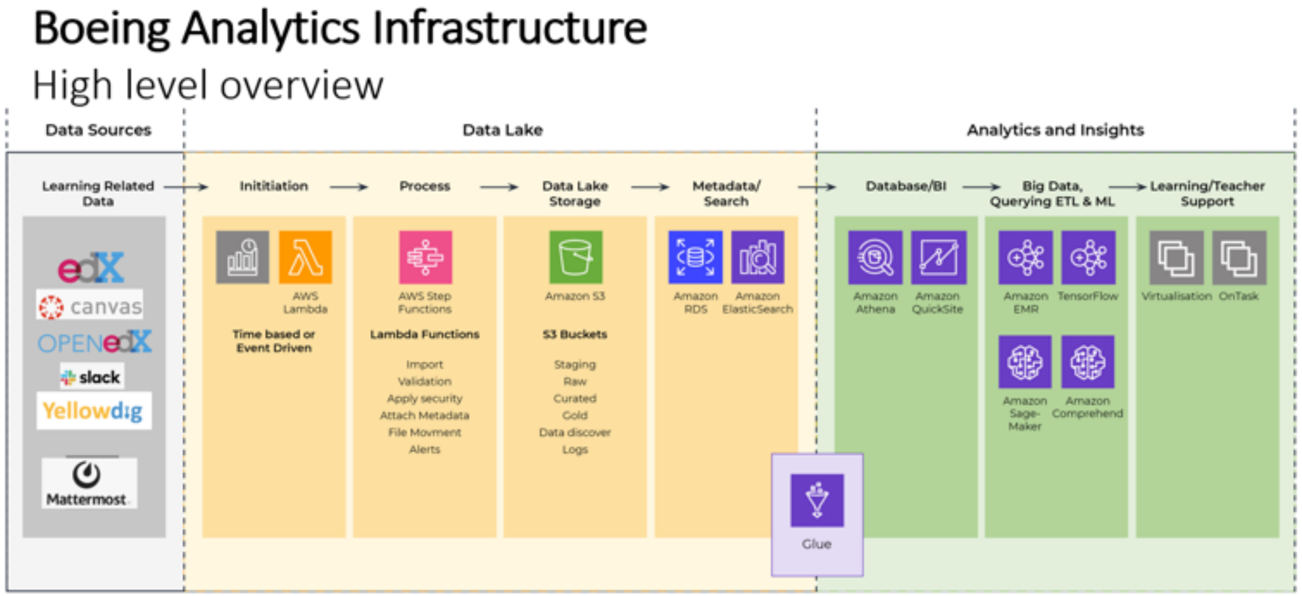
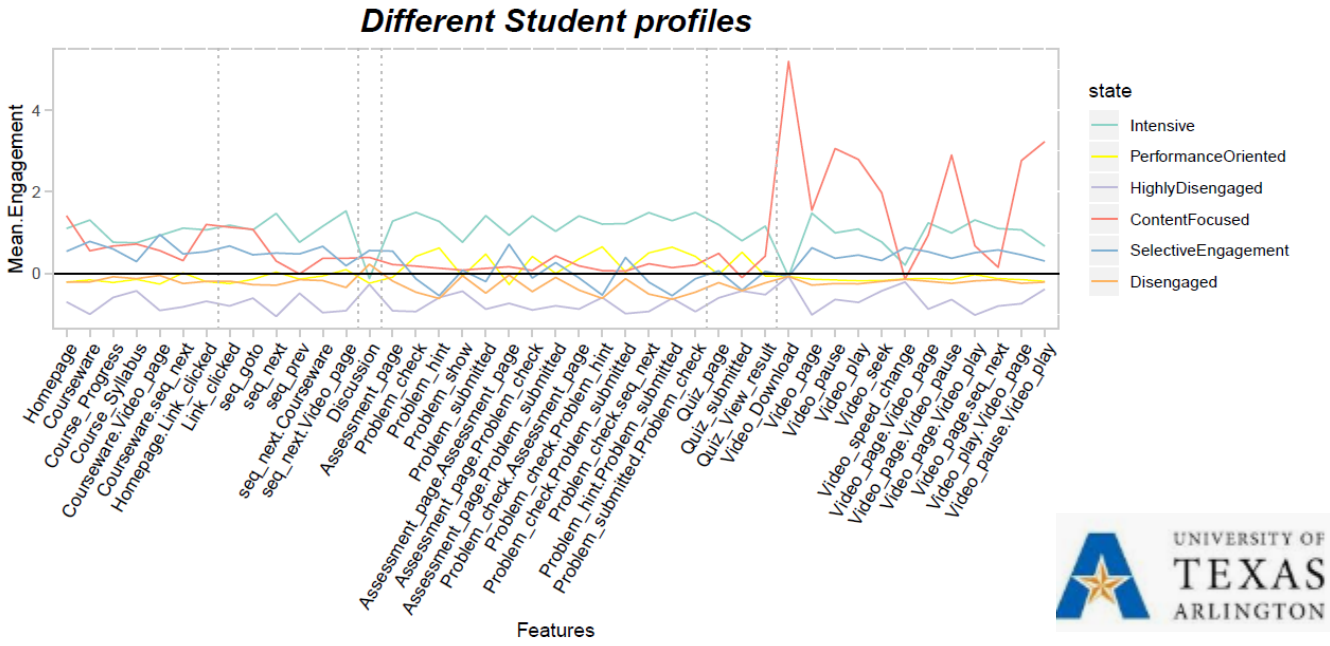
This visualization shows the trajectory of a more elegant student (99% passing grade) in the course Architecture of Complex Systems Fall 2016 (Total 16.35 hours)

PURDUE UNIVERSITY

"Visualization is uses a directed cyclic network graph to representation one student's interactions and movement across content modules. To reduce the visual size and complexity of network, course structure and modules are represented at the lowest-level course structure (Borner, Ginda & Richey,2017).

6. Federated Data Lake: Capture knowledge and advance personalized learning





This framework supports the need for life long adaptive learning through integrative point of need platforms.

- Assess deeper impact of learner actions on learner knowledge gains. Once we understand this, we can begin to provide adaptive feedback.
- Understanding learner proficiency and how to improve the process and guide learners to better learning strategies
- Measuring the types of skills that are critical to organizational success, but hard to assess or evaluate (team performance, peer effects, group metacognition, social networks, collaboration skills)
- Moving from traditional learning to personalized learning, using adaptive feedback and cognitive agents to guide learners
- Assessing and evaluating the best configuration of human and artificial cognition intersection in knowledge work.

University of Texas Arlington

Open Source – FAIR Data: https://en.wikipedia.org/wiki/FAIR_data

Increasingly, the integration of human and artificial intelligence raises new opportunities for instrumenting knowledge

Learner Information System

Learner profile/Demographics
Lesson planning
Scheduling
Enrolment
Assignments
Learning Curve - IProfecency data

Learning Environment

Log-trace data
Simulation data
Assessment
Social interaction
Content interaction
Intelligent tutoring system
Educational context data
Learner Record Store

Library Management System

E-media – Playbooks
InSite
BKN
Research publications
Journals

Instruments

Survey
BFI Psychometric Inventory
Questionnaire
Interview
Focus groups
Ethnography
Discourse Analysis

Multimodal

AR/VR
Video-tasic - Audio
Gesture
Psychophysiological data
EEG
fMRI

Social Media

NPL on:
Matters Most
Slack
Yellowdig
Online discussion boards
Sociotechnical networks
GitHub

Third-party Technology

Open_EdX
Neptune - AWS
AI/ML: Large-scale machine & Deep Reinforcement learning
BlockChain
xAPI

Example of Content interaction extracted – codified features and their description

Features	Description
Group 1: *Course Access*	
1. Homepage	No. of times homepage was opened
2. CourseProgress	No. of times course progress page was accessed
3. CourseSyllabus	No. of times course syllabus page was accessed
4. Courseware	No. of times module pages were opened
Group 2: *Course Navigation*	
5. LinkedClicked	No. of times hypertext links were clicked
6. Seq_next	No. of times next modules were clicked
7. Seq_prev	No. of times previous modules were clicked
8. Seq_goto	No. of times "goto" modules were clicked
Group 3: *Discussion*	
9. Discussion	No. of discussion events engaged in
Group 4: *Assessment*	
10. AssessmentPage	No. of times assessment page was opened
11. ProblemHint	No. of times hint to a problem was opened
12. ProblemShow	No. of times show answer to a problem was clicked
13. ProblemSubmitted	No. of times assessment was submitted
14. ProblemChecked	No. of times correctness of problem was checked
Group 5: *Quiz*	
15. QuizPage	No. of times quiz page was opened
16. QuizSubmitted	No. of times quiz was submitted
17. QuizViewResult	No. of times show answer to quiz was clicked
Group 6: *Video*	
18. VideoPage	No. of times video lecture page was opened
19. VideoPlay	No. of times video lecture was played
20. VideoPause	No. of times video lecture was paused
21. VideoSeek	No. of times video lecture was moved to a different time
22. VideoDownload	No. of times video lecture was downloaded
23. VideoSpeedChange	No. of times speed of video was changed

Barthakur, Kovanovic, Joksimovic, Dawson, Siemens & Richey, Understanding Online Student Engagement in MOOCs: Profiling Learners Using Latent Class Analysis. (2020)
Computers in Human Behaviour Journal (Pending)

Future of Work at the Human Technology Frontier:

Major transformation in advanced manufacturing – workforce reskilling are driven by combinations of convergence, machine learning, artificial intelligence, sensors, the internet-of things, cyber security and robotics.

- Developing the framework for fluid AI and ML coupled with human in the loop to assist with production anomalies without corruption (embedded intelligence)
- Develop Intelligent Cognitive Agents and integrated smart production devices and data systems that continuous sense cyber-physical systems which can assess the machine output and the user input
- Incorporate Cognitive Intelligent with factory wearable. Prototype natural interactions between human and machine and decouple the traditional user interface paradigm. Existing wearable's are in the factory and can already seamlessly collecting data but the fusion and context needs to be better understood.

Harnessing Data for 21st Century Science and Engineering:

Support basic research in math, statistics and computer science that will enable data-driven discovery through visualization, better data mining, machine learning

- New data capturing methods including AI and ML capability can establish mechanistic explanations of the flow of social knowledge and how social capital is leveraged – accessed in a networked production environment.
- The development of a new ontology of knowledge including machine data and human tasks will need needs to be model and understood. This will require a combination of machine learning, inputs source discovery, and directed human task elicitation (knowledge management).
- Capture cyber – physical data to train AI models that will surface deep learning patterns that are not cognitively visible to human cognition.
- Crowd source selected problems for university and student grand challenges (leverage the wisdom and open creativity of the network).

Intelligent Cognitive Assistants (ICA)

As cyber-physical systems evolve to incorporate more cognitive intelligence capabilities, the interface between them and their human users will also have to evolve to enable them to enhance their benefits to society.

Cognitive Psychology

- Perception vs Cognition
- Case Studies of Existing Digital Assistants
- Increasing Emotional Intelligence

Approaches to Artificial Intelligence

- Beyond Five Tribes of Machine Learning
- Cognitive AI
- Complementary Learning & Real-World Systems
- Better Understanding of Common Sense Reasoning (Essence of Things)
- Data Selection for Reinforcement Learning

Natural Interfacing

- Natural Language Processing
- Gestures, Perception, Vision, Sound, etc.
- Mixed-initiative Interaction
- Augmented Reality to increase trust

Data and Modeling

- Data Capture and Privacy
- Accurate, non-biased
- Or Sources of Biases are Modeled and Encoded
- APIs and Toolkits
- Different Data Types and Usages
- Handling sparse/incomplete data sets
- System Architectures, Beyond von Neumann Computing Architecture
- Energy Efficiency, High Performance
- Algorithms and Architectures
- Local Preprocessing for Speed, Security, Context, and Personal History
- Adaptable, Scalable, and Flexible
- Modular System Designs
- Neuromorphic Engineering Approaches

Intelligent Cognitive Assistants (ICA)

- **Large-scale machine learning** concerns the design of learning algorithms, as well as scaling existing algorithms, to work with extremely large data sets.
- **Deep learning**, a class of learning procedures, has facilitated object recognition in images, video labeling, and activity recognition, and is making significant inroads into other areas of perception, such as audio, speech, and natural language processing.
- **Reinforcement learning** is a framework that shifts the focus of machine learning from pattern recognition to experience-driven sequential decision-making. It promises to carry AI applications forward toward taking actions in the real world. While largely confined to academia over the past several decades, it is now seeing some practical, real-world successes.
- **Robotics** is currently concerned with how to train a robot to interact with the world around it in generalizable and predictable ways, how to facilitate manipulation of objects in interactive environments, and how to interact with people. Advances in robotics will rely on commensurate advances to improve the reliability and generality of computer vision and other forms of machine perception.
- **Computer vision** is currently the most prominent form of machine perception. It has been the sub-area of AI most transformed by the rise of deep learning. For the first time, computers are able to perform some vision tasks better than people. Much current research is focused on automatic image and video captioning.
- **Natural Language Processing**, often coupled with automatic speech recognition, is quickly becoming a commodity for widely spoken languages with large data sets. Research is now shifting to develop refined and capable systems that are able to interact with people through dialog, not just react to stylized requests. Great strides have also been made in machine translation among different languages, with more real-time person-to-person exchanges on the near horizon.
- **Crowdsourcing and human computation** research investigates methods to augment computer systems by making automated calls to human expertise to solve problems that computers alone cannot solve well.
- **Algorithmic game theory and computational social choice** draw attention to the economic and social computing dimensions of AI, such as how systems can handle potentially misaligned incentives, including self-interested human participants or firms and the automated AI-based agents representing them.
- **Internet of Things (IoT)** research is devoted to the idea that a wide array of devices, including appliances, vehicles, buildings, and cameras, can be interconnected to collect and share their abundant sensory information to use for intelligent purposes.
- **Neuromorphic computing** is a set of technologies that seek to mimic biological neural networks to improve the hardware efficiency and robustness of computing systems, often replacing an older emphasis on separate modules for input/ output, instruction-processing, and memory.
- **Collaborative systems** research investigates models and algorithms to help develop autonomous systems that can work collaboratively with other systems and with humans.