Visual Analytics & Learning Analytics in support of Data-Driven Decision Making

Michael Ginda, Naren Suri, Andreas Bueckle, and Katy Börner
Cyberinfrastructure for Network Science Center (CNS)
School of Informatics, Computing, and Engineering
Indiana University
@katycns

Knowledge Convergence Workshop at
9th International Learning Analytics and Knowledge Conference
https://lak19.solaresearch.org

Tempe, Arizona

March 4, 2019
Visual Analytics & Learning Analytics in support of Data-Driven Decision Making

Outline:

Context

Data Driven Decision Making
Visual Analytics
Learning Analytics
Exemplary set of IU Data Science courses, ‘Software Engineering’ jobs, and associated skills.
Job data was retrieved from LinkedIn and CareerBuilder and course data come from the IU course list. As can be seen, there are many skills (in orange) that are exclusively associated with courses or jobs; however, the skills in the middle interlink courses (in red) to jobs (in blue).
Empower students, teachers, and curriculum committee members to understand and discuss current and desirable student cohorts, key course trajectories, or the (gatekeeper) role that specific courses play.

Vertically, courses are arranged into four groups based on the department offering the course. Within each vertical grouping, the nodes are sorted by the total enrollment for the course with highest values on top. Node size encodes number of students enrolled; node color denotes overall GPA for the course.
Science & Technology vs. Education/Training vs. Jobs

Katy Börner, Olga Scrivner, Mike Gallant, Shutian Ma, Xiaozhong Liu, Keith Chewning, Lingfei Wu and James A. Evans

Need to study the (mis)match and temporal dynamics of S&T progress, education and workforce development options, and job requirements.

Challenges:
• Rapid change of STEM knowledge
• Increase in tools, AI
• Social skills (project management, team leadership)
• Increasing team size
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Study results are needed by:

• **Students:** What jobs will exist in 1-4 years? What program/learning trajectory is best to get/keep my dream job?

• **Teachers:** What course updates are needed? What curriculum design is best? What is my competition doing? How much timely knowledge (to get a job) vs. forever knowledge (to be prepared for 80 productive years) should I teach? How to innovate in teaching and get tenure?

• **Employers:** What skills are needed next year, in 5 years? Who trains the best? What skills does my competition list in job advertisements? How to hire/train productive teams?

What is ROI of my time, money, compassion?
Modeling and Visualizing Science and Technology Developments
National Academy of Sciences Sackler Colloquium, December 4-5, 2017, Irvine, CA

Rankings and the Efficiency of Institutions
H. Eugene Stanley | Albert-László Barabási | Lada Adamic | Marta González | Kaye Husbands Fealing | Brian Uzzi | John V. Lombardi

Higher Education and the Science & Technology Job Market
Katy Börner | Wendy L. Martinez | Michael Richey | William Rouse | Stasa Milojevic | Rob Rubin | David Krakauer

Innovation Diffusion and Technology Adoption
William Rouse | Donna Cox | Jeff Alstott | Ben Shneiderman | Rahul C. Basole | Scott Stern | Cesar Hidalgo

Modeling Needs, Infrastructures, Standards
Paul Trunfio | Sallie Keller | Andrew L. Russell | Guru Madhavan | Azer Bestavros | Jason Owen-Smith

nasonline.org/Sackler-Visualizing-Science
Visual Analytics - IVMOOC
Register for free: http://ivmooc.cns.iu.edu
The Information Visualization MOOC
ivmooc.cns.iu.edu

Students from more than 100 countries
350+ faculty members
#ivmooc
Data Visualization Literacy

Data visualization literacy (ability to read, make, and explain data visualizations) requires

• literacy (ability to read and write text, e.g., in titles, axis labels, legend),

• visual literacy (ability to find, interpret, evaluate, use, and create images and visual media), and

• data literacy (ability to read, create, and communicate data).

Being able to “read and write” data visualizations is becoming as important as being able to read and write text. Understanding, measuring, and improving data and visualization literacy is important for understanding STEAM developments and to strategically approach global issues.
Course Schedule

Part 1: Theory and Hands-On

• Session 1 – Workflow Design and Visualization Framework
• Session 2 – “When:” Temporal Data
• Session 3 – “Where:” Geospatial Data
• Session 4 – “What:” Topical Data

Mid-Term

• Session 5 – “With Whom:” Trees
• Session 6 – “With Whom:” Networks
• Session 7 – Dynamic Visualizations and Deployment

Final Exam

Part 2: Students work in teams on client projects.

Final grade is based on Homework and Quizzes (10%), Midterm (20%), Final (30%), Client Project (30%), and Class Participation (10%).
### Tasks

<table>
<thead>
<tr>
<th>LEVELS</th>
<th>MICRO: Individual Level</th>
<th>MESO: Local Level</th>
<th>MACRO: Global Level</th>
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</thead>
<tbody>
<tr>
<td>About</td>
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<table>
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<th>TYPES</th>
<th>Statistical Analysis</th>
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<th>Productivity of Russian life sciences research teams</th>
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<tr>
<td></td>
<td>page 44</td>
<td>page 135</td>
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<table>
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<tr>
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<th>Visualizing decision-making processes</th>
<th>Key events in the development of the video tape recorder</th>
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<tbody>
<tr>
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<td>page 25</td>
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<table>
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<tr>
<th>WHERE:</th>
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<th>Victorian poetry in Fumpa</th>
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</thead>
<tbody>
<tr>
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<td>page 52</td>
<td>page 109</td>
<td>page 157</td>
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</table>

<table>
<thead>
<tr>
<th>WHAT:</th>
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<th>Evolving patent holdings of Apple Computer, Inc. and Jerome Lemelson</th>
<th>Evolving journal networks in nanotechnology</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>page 56</td>
<td>page 50</td>
<td>page 159</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>WITH WHOM:</th>
<th>Network Analysis</th>
<th>World Finance Corporation network</th>
<th>Electronic and new media art networks</th>
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<tbody>
<tr>
<td></td>
<td>page 60</td>
<td>page 57</td>
<td>page 133</td>
</tr>
</tbody>
</table>

See Atlas of Science: Anyone Can Map, page 5
Needs-Driven Workflow Design

- **Stakeholders**
- **Data**
  - Read
  - Analyze
  - Visualize
  - Deployment

**Types and levels of analysis** determine data, algorithms & parameters, and deployment.

- Validation
- Interpretation

**DEPLOY**
- Visually encode data
- Overlay data
- Select visualiz. type
Needs-Driven Workflow Design

Validation
Interpretation

Stakeholders

Types and levels of analysis determine data, algorithms & parameters, and deployment

Data

READ

ANALYZE

DEPLOY

Visually encode data
Overlay data
Select visualiz. type

VISUALIZE

DEPLOY
# Visualization Framework

<table>
<thead>
<tr>
<th>Insight Need Types</th>
<th>Data Scale Types</th>
<th>Visualization Types</th>
<th>Graphic Symbol Types</th>
<th>Graphic Variable Types</th>
<th>Interaction Types</th>
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</thead>
<tbody>
<tr>
<td>• categorize/cluster</td>
<td>• nominal</td>
<td>• table</td>
<td>• geometric symbols</td>
<td>• spatial position</td>
<td>• overview</td>
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<td>• order/rank/sort</td>
<td>• ordinal</td>
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<td>• point</td>
<td>• zoom</td>
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<td>• interval</td>
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<td>• line</td>
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<td>(also outliers, gaps)</td>
<td>• ratio</td>
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<td>• area</td>
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<td>• surface</td>
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<td>• trends</td>
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<td>• volume</td>
<td>• history</td>
<td>• extract</td>
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<tr>
<td>(process and time)</td>
<td></td>
<td></td>
<td>• linguistic symbols</td>
<td>• projection</td>
<td>• link and brush</td>
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<tr>
<td>• geospatial</td>
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<td></td>
<td>text</td>
<td>• projection</td>
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<td>numerals</td>
<td>• distortion</td>
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<td>• correlations/relationships</td>
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<td>pictorial symbols</td>
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<td>icons</td>
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<td></td>
<td>statistical glyphs</td>
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# Graphic Variable Types Versus Graphic Symbol Types

<table>
<thead>
<tr>
<th>Spatial</th>
<th>Point</th>
<th>Line</th>
<th>Area</th>
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<tbody>
<tr>
<td>x</td>
<td><img src="image1" alt="Point Graphic" /></td>
<td><img src="image2" alt="Line Graphic" /></td>
<td><img src="image3" alt="Area Graphic" /></td>
</tr>
<tr>
<td>y</td>
<td><img src="image4" alt="Point Graphic" /></td>
<td><img src="image5" alt="Line Graphic" /></td>
<td><img src="image6" alt="Area Graphic" /></td>
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<td>z</td>
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<td><img src="image8" alt="Line Graphic" /></td>
<td><img src="image9" alt="Area Graphic" /></td>
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<th>Type</th>
<th>Description</th>
<th>Description</th>
<th>Description</th>
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<td>NA (Not Applicable)</td>
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<td><img src="image14" alt="Area Symbols" /></td>
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<td>quantitative</td>
<td>NA</td>
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<tr>
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<td>quantitative</td>
<td>NA</td>
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<td><img src="image25" alt="Value Bar" /></td>
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<tr>
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<td>quantitative</td>
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## Graphic Variable Types Versus Graphic Symbol Types

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Geometric Symbols</th>
<th>Linguistic Symbols</th>
<th>Pictorial Symbols</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>Point</td>
<td>Text</td>
<td>Images, icons, Statistical Glyphs</td>
</tr>
<tr>
<td>y</td>
<td>Line</td>
<td>Text</td>
<td></td>
</tr>
<tr>
<td>z</td>
<td>Area</td>
<td>Text</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Surface</td>
<td>Text</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Volume</td>
<td>Text</td>
<td></td>
</tr>
</tbody>
</table>

### Geometric Symbols

- **Point**: NA, NA, NA, NA
- **Line**: NA, NA, NA, NA
- **Area**: NA, NA, NA, NA
- **Surface**: NA, NA, NA, NA
- **Volume**: NA, NA, NA, NA

### Linguistic Symbols

- Text

### Pictorial Symbols

- Images, icons, Statistical Glyphs

### Color

- Value: quantification
- Hue: qualitative
- Saturation: quantification

### Form

- Size: quantification
- Shape: qualitative
- Rotation: quantification
- Curvature: quantification
- Angle: quantification
- Closure: quantification

### Texture

- Spacing: quantification
- Granularity: quantification
- Pattern: qualitative
- Orientation: quantification
- Gradient: quantification

### Surface

- Blur: quantification
- Transparency: quantification
- Shading: quantification

### Stereoscopic Depth

- Point in foreground, background
- Line in foreground, background
- Area in foreground, background
- Surface in foreground, background
- Volume in foreground, background

### Motion

- Speed: quantification
- Velocity: quantification
- Rhythm: quantification

### Some table cells are left blank to encourage future exploration of combinations.
Learning Analytics
Learning Analytics

**Empowering Teachers:** How to make sense of the activities of thousands of students? How to guide them?

**Empowering Students:** How to navigate learning materials and develop successful learning collaborations across disciplines and time zones?

**Empowering Researchers:** How do people learn? What pedagogy works (in a MOOC) and when?

**Empowering MOOC Platform Designers:** What technology helps and what hurts?
Visualizing IVMOOC Data

Data was collected from different sources:

- 1,901 students registered via GCB (1215 male/557 female)
- 52,557 slide downloads from our server
- 18,893 video views via YouTube
- 193 accounts made 730 tweets
- 134 students took 183 exams in GCB
- 674 remarks on 215 different forum threads in Drupal
- 64 students submitted projects via Drupal
Learning Analytics

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Student Registration and Activity

Jan. 22: Course Starts
March 11: Final Exam Deadline
Student Registration and Activity

IVMOOC Student Activity (Achievement Badge)
Student Registration and Activity

1215 male students
557 female students
Student Registration and Activity

1215 male students
557 female students
Student Registration and Activity

Novice IVMOOC Student Activity

Activity Types
- Registration
- Exam
- YouTube
- Twitter

Date
- Jan
- Mar
- May

Student
- 0
- 500
- 1000
- 1500
Student Registration and Activity

Expert IVMOOOC Student Activity

Activity Types:
- Blue circles: Registration
- Red triangles: Exam
- Green squares: YouTube
- Purple stars: Twitter

Date:
- Jan
- Mar
- May
Custom interactive visualizations of IVMOOC student engagement and performance data, explore functionality online at http://goo.gl/TYixCn
Figure 1: Analysis types vs. user needs.

Future Work
Data Visualization Literacy: Definitions, Conceptual Frameworks, Exercises, and Assessments

Katy Börner¹, Andreas Bueckle¹, Michael Ginda¹

¹Indiana University

Submitted to Proceedings of the National Academy of Sciences of the United States of America

In the information age, the ability to read and construct data visualizations becomes as important as the ability to read and write text. However, while standard definitions and theoretical frameworks to teach and assess textual, mathematical, and visual literacy exist, current data visualization literacy (DVL) definitions and frameworks are not comprehensive enough to guide the design of DVL teaching and assessment. This paper introduces a conceptual framework (DVL-FW) that was specifically developed to define, teach, and assess DVL. The holistic DVL-FW promotes both the reading and construction of data visualizations, a pairing analogous to that of both reading and writing in textual literacy and understanding and applying in mathematical literacy. Specifically, the DVL-FW defines a hierarchical typology of core concepts and details the process steps that are required to extract insights from data. Advancing the state of the art, the DVL-FW interlinks theoretical and procedural knowledge and showcases how both can be combined to design curricula and assessment measures for DVL. Earlier versions of the DVL-FW have been used to teach DVL to more than 8,500 residential and online students, and results from this effort have helped revise and validate the DVL-FW presented here.

measurement, and estimation,” as well as an “understanding of ratio concepts, notably fractions, proportions, percentages, and probabilities” (6). PISA defines it as “an individual’s capacity to formulate, employ, and interpret mathematics in a variety of contexts,” including “reasoning mathematically and using mathematical concepts, procedures, facts and tools to describe, explain and predict phenomena.” PISA administers standardized tests for math, problem-solving, and financial literacy (7). The PISA 2015 Draft Mathematics Framework (8) explains the theoretical underpinnings of the assessment, the formal definition of mathematical literacy, the mathematical processes which students undertake when using mathematical literacy, and the fundamental mathematical capabilities that underlie those processes. Visual literacy was initially defined as a person’s ability to “discriminate and interpret the visible actions, objects, and symbols natural or man-made, that he encounters in his environment” (9). In 1978, it was defined “as a group of skills which enable an individual to understand and use visuals for intentionally communicating with others” (10). More recently, the Association of College and Research Libraries (ACRL) defined standards, performance indicators, and learning outcomes for visual literacy (11, 12). In the academic setting, Averinou (13) developed and validated a visual literacy index by running focus groups of visual

PNAS, 2019
https://www.pnas.org/content/early/2019/01/29/1807180116
Next Generation IVMOOC

**Instructor:** Victor H. Yngve Distinguished Professor Katy Börner & CNS Team, ISE, SICE, IUB

**Duration:** 6 weeks x 5 hours = 30 hours (3 CEUs)

**Format:** Online | Theory and Hands-on Instruction, Concept Questions, Graded Assignments, Case Studies, Discussions

**Next Run Starts:** March 25, 2019

**Covers:**
Temporal, geospatial, topical (linguistic), network analyses and 60+ visualization types

**Tools:** Tableau, Gephi, BI,

**Industry case studies** such as
- Acting on customer complaints data.
- Improving communication/traffic flows.
- Understanding web page usage.
- Visualizing online shopping behavior.
- Optimizing supply chains.
- Reducing customer/supplier churn.
- Monitoring emerging R&D areas.
- Workforce development planning.

https://visanalytics.cns.iu.edu
Visual Analytics Certificate

Advance your skills in one of the most in demand careers through this online course focused on understanding and creating data visualizations that translate complex data into actionable insights.

Register: tinyurl.com/VACRegister

Learn from Experts
Connect with industry professionals and leading researchers.

Evolve Yourself
Gain forever knowledge and skill-up in powerful data visualization tools.

Make a Difference
Embrace data-driven decision-making in your personal and professional life.

https://visanalytics.cns.iu.edu
Next Generation IVMOOC

Systematic study of how different student cohorts learn best—using Mechanical Turk formal user studies, e.g., to optimize horizontal transfer:

- **Table**
  - Columns by rows
  - Column | Row
  - \( x \) | \( y \)
  - 0 | 3
  - 2 | 11
  - 4 | 19
  - 6 | 27
  - 8 | 35

- **Graph**
  - x-y coordinates
  - linear/log scale

- **Map**
  - Latitude/longitude

- **Network**
  - Local similarity

Horizontal Transfer
Next Generation IVMOOC

Systematic study of how different student cohorts learn best—using Learning Analytics to optimize scaffolding and learning trajectories:

<table>
<thead>
<tr>
<th>Insights</th>
<th>Report</th>
</tr>
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<tbody>
<tr>
<td>Trends, clusters, outliers</td>
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</tr>
<tr>
<td>Interactivity</td>
<td>Do select best type(s) of</td>
</tr>
<tr>
<td>Zoom, filter, details-on-demand</td>
<td>Graphic variables</td>
</tr>
<tr>
<td>Graphic variables</td>
<td>Graphic symbols</td>
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<tr>
<td>Position, color, size, shape code</td>
<td>Visualizations</td>
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<tr>
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<td>Given</td>
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<td>Geometric, linguistic, or pictorial</td>
<td>Data &amp; Insight Needs</td>
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<tr>
<td>Visualizations</td>
<td></td>
</tr>
<tr>
<td>Table, graph, map, network</td>
<td></td>
</tr>
</tbody>
</table>
References


http://www.pnas.org/content/vol101/suppl_1

Börner, Katy (2010) **Atlas of Science: Visualizing What We Know.** The MIT Press.  
http://scimaps.org/atlas

Scharnhorst, Andrea, Börner, Katy, van den Besselaar, Peter (2012) **Models of Science Dynamics.** Springer Verlag.


All papers, maps, tools, talks, press are linked from http://cns.iu.edu
These slides are at http://cns.iu.edu/presentations.html

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Mapping Science Exhibit Facebook: http://www.facebook.com/mappingscience