Design Activity Framework: Investigating the Data Visualization Design Process

by Sean P. McKenna

June 1st, 2017
Dissertation Defense
What is Visualization Design?

- process to create data visualizations
- work with users to identify their problems and needs
- ideas evolve and systems are built
Motivating Example

- more devices
- more data
- greater risk
Cyber Security

• analysts work to protect our data

• many challenges exist:
  • adapting attacks
  • growing amounts of data
  • devil is in the details
  • missing information
  • limited access for designers
Redesign Project

Design Activity Framework for Visualization Design
Visualization Design: Questions & Goals

- what am I trying to create? ➔ achievable
- how do I compare and select these outcomes? ➔ justifiable
- what actions can I perform? ➔ discoverable
- where should I go to next? ➔ flexible
- what are the steps I should perform? ➔ actionable
Design Activity Framework

• data visualization design process model

• guide and support creation of visualization systems

• describe and capture design flexibility

- understand
- ideate
- make
- deploy

- design activity
- motivation
- artifacts
- methods
Design Activity Framework: Components

- visualization artifacts
- maps to design decisions
- table of design methods
- design timelines
- activity worksheets
Design Activity Framework: Projects

• formative and summative projects

• validated the framework:
  • internally, via a design study
  • externally, with students

• reflected on other research projects:
  • technique-driven
  • evaluation
Related Work: Nine Stage Framework

• process for design studies

• planning to reflection phases

• missing aspects for visualization design

[Sedlmair, Meyer, Munzner 2012]
Related Work: Nested Model

- four levels for design decisions
- decisions cascade internally
- rationale & decision making
- supports knowledge transference

[domain characterization]
[data/task abstraction design]
[encoding/interaction technique design]
[algorithm design]

[Munzner 2010]
Related Work: Visualization Models

- connect **actions** we take with **decisions** we make: justifiable

**process models**

**decision models**

[Diagrams showing process models and decision models]

[Sedlmair, Meyer, Munzner 2012]

[Munzner 2010]
Related Work: Process Models

- support a **flexible** and **achievable** design process

![engineering process](image)

![creative process](image)

[Tory, Möller 2004] [Kumar 2012]
Related Work: Design Pedagogy

- teach design process: both **discoverable** and **actionable**

**prescriptive choices**

[He, Adar 2017]

**guided steps**

[Roberts, Headleand, Ritsos 2016]
A Design Activity

Four Activities

**where am I?**
- motivation

**what is my goal?**
- artifacts

**how do I get there?**
- methods

**understand**
- specific purpose behind the methods and actions that are performed within an activity, characterized by which level or levels of the nested model they address

**ideate**
- specific, unique results of an activity, characterized by which level or levels of the nested model they address

**make**
- actions or techniques that a designer employs to either generate or evaluate artifacts

**deploy**
## Four Design Activities

<table>
<thead>
<tr>
<th>Understand</th>
<th>Ideate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>motivation:</strong> finding the needs of the user</td>
<td><strong>generate good ideas to support needs</strong></td>
</tr>
<tr>
<td><strong>artifacts:</strong> sets of design requirements</td>
<td><strong>sets of ideas</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Make</th>
<th>Deploy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>concretize ideas, make them tangible</strong></td>
<td><strong>bring a prototype into effective action</strong></td>
</tr>
<tr>
<td><strong>sets of prototypes</strong></td>
<td><strong>visualization system</strong></td>
</tr>
</tbody>
</table>
Example of a Deploy Activity

- software analysis of a visualization system
Example of a Understand Activity

- qualitative coding of cognitive task analysis papers

<table>
<thead>
<tr>
<th>category</th>
<th>sub-category</th>
<th>sub-sub-category</th>
<th>evidence</th>
<th>author</th>
<th>pages</th>
<th>notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>communities</td>
<td>attackers</td>
<td></td>
<td>&quot;... increasingly sophisticated technical and social attacks from organized criminal operations&quot;</td>
<td>D'Amico</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>data</td>
<td>external</td>
<td>website</td>
<td>&quot;information published on hacker websites&quot;</td>
<td>D'Amico</td>
<td>29</td>
<td></td>
</tr>
<tr>
<td>data</td>
<td>processed</td>
<td>report</td>
<td>&quot;incident report, intrusion set, problem set from other organizations, information about the source and or sponsor of attack&quot; &amp; &quot;incident reports are [often] textual documents&quot;</td>
<td>D'Amico</td>
<td>35</td>
<td>eg, power point, word doc, video, podcast, ...</td>
</tr>
<tr>
<td>data</td>
<td>raw</td>
<td>packets (data, netflow)</td>
<td>&quot;network packet traffic, netflow data or host-based log data&quot;</td>
<td>D'Amico</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>design guidelines</td>
<td>tutorial</td>
<td></td>
<td>&quot;tutorial on how to get started; not just the user’s manual .... certification process so people can become certified&quot;</td>
<td>Erbacher</td>
<td>212</td>
<td></td>
</tr>
<tr>
<td>design guidelines</td>
<td>uncertainty</td>
<td>visualization</td>
<td>&quot;visualization should have a weight based on the accuracy of info&quot; &amp; &quot;force-directed graphs where trust is the primary spring force&quot;</td>
<td>Erbacher</td>
<td>210,212</td>
<td></td>
</tr>
<tr>
<td>other</td>
<td>metaphor</td>
<td></td>
<td>&quot;Cyber security is essentially a human-on-human adversarial game played out by automated avatars.&quot;</td>
<td>Fink</td>
<td>46</td>
<td></td>
</tr>
<tr>
<td>phases</td>
<td>situational</td>
<td>awareness</td>
<td>&quot;During the first stage, a CND analyst acquires data about the monitored environment, which is typical of the perceptual stage of situation awareness.&quot;</td>
<td>D'Amico</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>responsibilities</td>
<td>communication</td>
<td></td>
<td>&quot;importance of analyst communication in the data transformation&quot;</td>
<td>D'Amico</td>
<td>30</td>
<td></td>
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<tr>
<td>roles</td>
<td>managers</td>
<td></td>
<td>&quot;most were active analysts; a few were managers&quot;</td>
<td>D'Amico</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>roles</td>
<td>network analyst</td>
<td></td>
<td>&quot;computer network defense (CND) analysts&quot;</td>
<td>D'Amico</td>
<td>19</td>
<td></td>
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<tr>
<td>workflows</td>
<td>investigate</td>
<td></td>
<td>&quot;If a vulnerability scan returned a suspect IP address, he would then have to go through several different tools in different windows to get information about the IP, such as the host name, its location in the network or building, its OS version and update status, its owner, and the owner’s phone number.&quot;</td>
<td>Fink</td>
<td>49</td>
<td></td>
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</tbody>
</table>
Example of a Ideate Activity

- concept sketches & wireframes
Example of a Make Activity

- digital mockups
Mapping Design Decisions

- Domain characterization
- Data / task abstraction
- Encoding / interaction technique
- Algorithm design

[ decision matrix ]

Munzner 2010
# Discovering Design Methods

<table>
<thead>
<tr>
<th>#</th>
<th>method</th>
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<th>g</th>
<th>i</th>
<th>e</th>
<th>m</th>
<th>d</th>
<th>v</th>
<th>definition</th>
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<tbody>
<tr>
<td>1</td>
<td>A/B testing</td>
<td></td>
<td>g</td>
<td>e</td>
<td></td>
<td>g</td>
<td>e</td>
<td></td>
<td>“compare two versions of the same design to see which one performs statistically better against a predetermined goal” [25]</td>
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<tr>
<td>2</td>
<td>activity map</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td>“structuring activities of stakeholders and showing how they relate to one another…. take a list of activities gathered during research and see how they are grouped based on their relationships” [25]</td>
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<td>3</td>
<td>AEIOU framework</td>
<td></td>
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<td>g</td>
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<td></td>
<td>“organizational framework reminding the researcher to attend to text, document, and code information under a guiding taxonomy” [25]</td>
</tr>
<tr>
<td>4</td>
<td>affinity diagramming</td>
<td></td>
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<td>g</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>“process used to externalize and meaningfully cluster observations and insights from research, keeping design teams grounded as they design” [25]</td>
</tr>
<tr>
<td>5</td>
<td>algorithmic performance</td>
<td></td>
<td>g</td>
<td></td>
<td></td>
<td></td>
<td>g</td>
<td></td>
<td>“quantitatively study the performance or quality of visual algorithms…. common examples include measurement of rendering speed or memory performance” [30]</td>
</tr>
<tr>
<td>6</td>
<td>analogical reasoning</td>
<td></td>
<td></td>
<td>g</td>
<td></td>
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<td></td>
<td></td>
<td>“cognitive strategy in which previous knowledge is accessed and transferred to fit the current requirements of a novel situation” [30]</td>
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<tr>
<td>7</td>
<td>appearance modeling</td>
<td></td>
<td>g</td>
<td></td>
<td></td>
<td>g</td>
<td></td>
<td></td>
<td>“refined model of a new idea that emphasizes visual styling” [25]</td>
</tr>
<tr>
<td>8</td>
<td>artifact analysis</td>
<td></td>
<td>g</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>“systematic examination of the material, aesthetic, and interplay of the qualities of objects contributes to an understanding of their political, social, and cultural contexts” [25]</td>
</tr>
</tbody>
</table>
Design Process Timelines

• built to capture design flow
• **flexible**; support messiness

• two basic **movement principles**
  1. **forward** movement is **ordered**
  2. activities can be **nested** or conducted in **parallel**
Design Process Timelines

- redesign project

- Shotviewer
  [Kerzner et al. 2015]

- Variant View
  [Ferstay, Nielsen, Munzner 2013]
Design Activity Framework Summary

• design activities with visualization artifacts
• map to nested model decisions
• design methods for each activity
• plan and communicate with timelines
Conducting a Design Study

• validate the framework

• track visualization artifacts

• employ new design methods

• can this lead to success?

BubbleNet: A Cyber Security Dashboard for Visualizing Patterns
S. McKenna, D. Staheli, C. Fulcher, and M. Meyer, CGF, 2016
Data and Task Abstraction

- **network record**: metadata associated with the communication between two computers

- **pattern**: collection of *network records* that represent recurring or abnormal behavior

- **tasks**: *discover* & *present*
  - dashboards show overview
  - aggregation & deviation
Dashboard Design Process

- framework guided us across multiple discourse channels [Wood, Beecham, Dykes 2014]
Personas Method

- identified potential users
- flow of information & decisions
- focused the final design:
  - analysts and managers

Unlocking User-Centered Design Methods for Building Cyber Security Visualizations
S. McKenna, D. Staheli, and M. Meyer, VizSec, 2015
Data Sketches

- data-driven sketches, test our abstractions
  [Lloyd & Dykes 2011]
- feedback from analyst
- location-based map encoding
BubbleNet Dashboard

- location view
- temporal views
- attribute bullet charts
- record details
- selection overview
BubbleNet Dashboard Interactions
Dashboard Evaluation

- usability scores with five analysts, four managers [Sauro 2011]
  - “I could write a splunk query to do this, but this is easier”
Design Study Summary

• successful design study
  • evaluation with users
  • tool deployments

• guided by the framework

• captured a rich description of the design process
Evaluating with Worksheets

- external validation of the framework
- increase actionability with concrete steps
- worked with students on class projects
- can novices follow the framework?

Worksheets for Guiding Novices Through the Visualization Design Process
S. McKenna, A. Lex, and M. Meyer, (to be submitted to Pedagogy of Data Vis. Workshop), 2017
Worksheet Evaluation

• lecture on visualization design

• mentored group projects with 13 students
  • weekly progress meetings
  • answered questions
Evaluation Results

• design worksheets helped students learn

• most helpful: *understand* and *ideate*
  • both “helped to get the project off the ground”
  • “critique of one’s own design was most helpful”

• focused student projects & provided a “snapshot in time”

• steps: “it’s like a checklist to make sure everything is covered”
Application to Other Research

• beyond problem-driven work, research in:
  • technique development
  • evaluation methods

• what role does design play?

• does the framework lead to ruminations?
s-CorrPlot Technique

- encoding correlation in a scatterplot

s-CorrPlot: An Interactive Scatterplot for Exploring Correlation
S. McKenna, M. Meyer, C. Gregg, and S. Gerber, JCGS, 2016
s-CorrPlot Interactions
Designing for Techniques

• “incomplete problem”: tool needed more data

• identified new pitfalls for design studies
  • team miscommunication
  • prioritized novel idea
  • deployed too early

• similar process, except algorithmic decisions
A Visual Introduction to Machine Learning

In machine learning, computers apply statistical learning techniques to automatically identify patterns in data. These techniques can be used to make highly accurate predictions.

Using a data set about homes, we will create a machine learning model to predict if homes in New York are more likely to be sold in San Francisco.

Visual Narrative Flow: Exploring Factors Shaping Data Visualization Story Reading Experiences
S. McKenna, N. Henry Riche, B. Lee, J. Boyd, and M. Meyer, CGF, 2017
Results of Crowdsourced Evaluation

- 240 participants, Amazon MTurk
  - compared two conditions each
  - survey on engagement
Designing for Evaluation

• hypotheses & story “prototypes” as artifacts

• pilots and exploratory studies employed

• vital to record details of experimental design

• guidelines established lack generalizability
Discussion

• design models may change and grow with new:
  • activities
  • methods
  • artifacts
  • decisions

• continue to evaluate the worksheets in the classroom and beyond

• apply model to other types of research

• consider the role of software engineering, e.g., agile
Conclusion

• design activity framework provides:
  • visualization artifacts
  • mapping to decisions
  • table of methods
  • timelines
  • worksheets

• validated with a design study
• evaluated worksheets with students
• reflected on other types of research
Acknowledgments

• committee:
  • Miriah Meyer, Alex Lex, Tammy Denning, Jim Agutter, Nathalie Henry Riche

• family, friends, & mentors

• SCI & SoC staff

• colleagues & co-authors

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Related Publications


Thank You!

http://mckennapsean.com/projects/design-activity-framework/

http://design-worksheets.github.io/
Design Method: Paper Prototyping

“create a **paper-based simulation of an interface** to test interaction with a user”

Maguire, “Methods to support human-centred design” 2001

Lloyd & J. Dykes, “Human-centered approaches in geovisualization design” 2011
“personal letter written to a product… [to reveal] profound insights about what people value and expect”

Martin & Hanington, Universal Methods of Design: 100 Ways to Research, 2012
Design Timeline

- May: plan, artifact analysis
- Jun: literature review, open coding
- Jul: identify key opportunities, concept sketches
- Aug: analysts interview, developer interview, wireframes
- Sep: interface mockups, time series ideation
- Oct: developer prototype
- Nov: A/B testing + questionnaire

Final deadline
Design Timeline #2
BubbleNet Sketches
BubbleNet Weighted Matrix

|   | A    | B    | C    | D    | E    | F    | G    | H    | I    | J    | K    | L    | M    | N    | O    | P    | Q    | R    | S    | T    | U    | V    | W    | score |
|---|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| 1 | idea |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| 2 |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| 3 | priority | 3 | 3 | 5 | 3 | 3 | 3 | 1 | 5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 41 | 26 |
| 4 | mission-A | 0 | 1 | 2 | 1 | 1 | 1 | 0 | 2 | 0 | 0 | 1 | 2 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 40 | 26 |
| 5 | mission-B | 1 | 1 | 1 | 1 | 2 | 0 | 2 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 39 | 25 |
| 6 | mission-C | 1 | 1 | 1 | 1 | 2 | 0 | 2 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 38 | 25 |
| 7 | report-A (spec) | 0 | 2 | 0 | 1 | 1 | 0 | 0 | 2 | 1 | 2 | 0 | 0 | 1 | 2 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 45 | 30 |
| 8 | report-B | 2 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 43 | 28 |
| 9 | report-C | 2 | 1 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 2 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 38 | 25 |
| 10 | report-D | 1 | 1 | 0 | 0 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 21 | 14 |
| 11 | map-A | 2 | 1 | 1 | 2 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 43 | 28 |
| 12 | map-B | 1 | 1 | 1 | 2 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 45 | 30 |
| 13 | mg-A | 2 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 2 | 0 | 1 | 1 | 2 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 40 | 26 |
| 14 | mg-B | 1 | 1 | 1 | 1 | 1 | 0 | 2 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 33 | 21 |
| 15 | mg-C | 2 | 1 | 1 | 1 | 2 | 0 | 2 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 42 | 27 |
| 16 | st-A | 2 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 42 | 27 |
| 17 | st-B | 2 | 1 | 2 | 1 | 2 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 42 | 27 |
| 18 | rm-A | 1 | 1 | 1 | 1 | 2 | 0 | 2 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 42 | 27 |
| 19 | f-i | 1 | 2 | 2 | 2 | 1 | 0 | 1 | 0 | 1 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 47 | 30 |
| 20 | f-ii | 0 | 1 | 1 | 1 | 2 | 0 | 2 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 47 | 31 |
| 21 | f-iii | 1 | 2 | 2 | 0 | 0 | 1 | 2 | 2 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 47 | 31 |
| 22 | f-iv | 0 | 1 | 0 | 1 | 1 | 0 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 29 | 19 |
BubbleNet Mockup
# BubbleNet Dataset

<table>
<thead>
<tr>
<th><strong>DATA</strong></th>
<th><strong>SOURCE</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Geolocation</td>
<td>MaxMind database (IPs)</td>
</tr>
<tr>
<td>Reports</td>
<td>IT security analyst</td>
</tr>
<tr>
<td>Alerts</td>
<td>external network – IDS system</td>
</tr>
</tbody>
</table>

- **external** traffic from around the globe
- **detailed** information on two recent incidents
- **millions** of alerts
BubbleNet Prototype

Thursday 3 July 2014
23:58:19 (eastern)

Daily Summary
199,908 alerts & 1 report  ↓ 6.1% fewer alerts

Bar Chart Axes
Log

Priorities of Alerts
High
Medium
Low

Categories of Alerts
Potential
Attempt
Detected
Other

#3 - Beijing China IP addresses are sending to public addresses

Dates: June 29, 2014 - ?
Intent: network attack
Result: unknown
Methodology:

Beijing, China: 32,287 alerts
BubbleNet Prototype #2
BubbleNet Patterns
Visual Narrative Flow: Design Space

- **Navigation Input**: button, scroll, slider
- **Navigation Progress**: text, dots, vis
- **Story Layout**: document, slideshow, hybrid
- **Story Progression**: linear, linear skip, tree/graph
- **Level of Control**: over: text, vis, transitions
  and how: discrete, continuous, hybrid
- **Role of Visualization**: equal, figure, annotated
- **Navigation Feedback**: text, vis, widget
<table>
<thead>
<tr>
<th>#</th>
<th>title</th>
<th>navigation input</th>
<th>level of control</th>
<th>navigation progress</th>
<th>role of visualization</th>
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<tr>
<td>1</td>
<td>A Visual Introduction to Machine Learning</td>
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<td>Scientific Proof that Americans are Completely More Productive</td>
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<td>3</td>
<td>Fewer Helmets, More Deaths</td>
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<td>4</td>
<td>A 3-D View of a Chart That Predicts The Economy</td>
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<td>A Visual Analysis of Battle at the Berries</td>
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<td>Budget Forecasts, Compared With Reality</td>
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<td>7</td>
<td>Human Development Trends, 2005</td>
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<td>8</td>
<td>Diary of a Food Tracker</td>
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<td>9</td>
<td>How Americans Die</td>
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Visual Narrative Flow: Conditions
Visual Narrative Flow: Preferences

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Values range from 0 to 20.