Analysis and Implications of Data Visualization Courses at World-Renowned Universities

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Abstract

[Purpose/Significance] By analyzing data visualization-related courses in internationally renowned universities and summarizing their curriculum design and characteristics, this study aims to provide references for data visualization course construction in library and information science departments in China. [Method/Process] Using web survey and content analysis methods, 53 universities among the QS global top 100 that have offered data visualization-related courses were selected, and a detailed study of these courses was conducted from four dimensions: prerequisite knowledge, teaching plans, course content, and assessment methods, to analyze their practical progress and characteristics. [Results/Conclusion] Among the QS global top 100 universities, 53 have actively participated in data visualization course teaching, and the surveyed cases demonstrate teaching characteristics including high recognition, prominent interdisciplinary features, integration of theory and practice, and clear trend toward professional specialization. Library and information science departments in China can fully reference the DVL-FW process model to design the core content of data visualization courses and learn from the practical experience of internationally renowned universities, while also emphasizing the learning of auxiliary skills such as tool learning, critical thinking, and ethics.

Full Text

Analysis and Enlightenment of Data Visualization Courses in Internationally Renowned Universities

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Abstract

[**Purpose/Significance**] This study analyzes data visualization courses offered by internationally renowned universities, summarizing their curriculum structures and characteristics to provide reference for data visualization course development in Chinese library and information science (LIS) departments. [**Method/Process**] Through web-based investigation and content analysis, we examined 53 universities among the QS Global Top 100 that offer data visualization courses, conducting detailed research across four dimensions: prerequisite knowledge, teaching plans, course content, and assessment methods to analyze their practical implementation and features. [**Result/Conclusion**] Among QS Global Top 100 universities, 53 have actively engaged in data visualization education, with 113 courses identified. The findings reveal four key characteristics: high institutional recognition, prominent interdisciplinary features, integration of theory and practice, and an emerging trend toward specialized degree programs. Chinese LIS departments can reference the DVL-FW process model to design core curriculum content, learn from international best practices, and emphasize auxiliary skills such as tool proficiency, critical thinking, and ethics education.

Keywords: universities; data visualization literacy; curriculum construction; DVL-FW model
Classification Number: G250

Data visualization literacy refers to the ability to accurately interpret and construct meaning from data visualizations to solve data-related problems [1], emphasizing data-driven visualization and big data decision-making capabilities. The level of data visualization literacy will directly impact people's ability to gain insights from data or big data in the future. Prominent scholars such as K. Börner have proposed that data visualization literacy could become as fundamental as textual and numerical literacy, with its emergence representing a significant growth opportunity for the LIS discipline [1]. Education targeting data visualization literacy, particularly related curriculum development, will become a key focus for library and information institutions.

2.1 Research on Data Visualization Courses

Data visualization courses represent an important approach to data visualization literacy education in LIS departments, yet research on these courses remains in its infancy both domestically and internationally. Internationally, beyond theoretical studies on course objectives, curriculum design, and learning outcomes [3], most research focuses on practical implementation from three perspectives: (1) tool usage and evaluation, such as VTK (Visualization Toolkit) [4], the "VisTrails" system used at the University of Utah [5], and Google Charts and Maps [6]; (2) pedagogical innovations, including incorporating real-world data and scenarios [7], Vizitcards workshops [8], and game-driven teaching [3]; and (3) case studies of specific courses, such as the introductory visualization course at the University of Aveiro [9] and the information visualization course at Linnaeus University [10].

Domestic research on data visualization courses is relatively limited, concentrating on three areas: (1) comparative studies of domestic and international universities, including investigations of visualization courses among iSchool members across six aspects (basic information, prerequisites, content, objectives, teaching methods, and assessment) [11] and analyses of data visualization MOOCs regarding teaching content and difficulty [12]; (2) local curriculum development and tool creation, such as constructing a three-dimensional curriculum system based on "knowledge dimension, workplace dimension, and user dimension" [13], introducing flipped classroom models [14], and Beijing Normal University's self-developed "VisMis" system for data visualization courses [15]; and (3) data visualization courses in other disciplines, such as art schools offering visualization courses involving hierarchical teaching models and contextualized instruction.

2.2 Research on Data Visualization Course Content

Current research reveals no unified framework for core content in data visualization education. For instance, the University of Aveiro's introductory visualization course covers basic concepts, applications, human visual systems, visual representation of quantitative information, visualization frameworks, techniques and theoretical foundations, data characteristics, and visualization products [9]. iSchool visualization courses include introductions to basic concepts and theories, software and programming languages, and applied learning of related technologies [11]. Among 57 data visualization MOOCs, content covers fundamental theories, various visualization methods and techniques, chart types, tools, applications, evaluation, and development trends [12]. While common understandings exist, the academic community lacks consensus on what constitutes core versus secondary content. Course content design should follow scientific principles rather than simply aggregating related knowledge.

Given that data visualization course research remains nascent and existing surveys focus primarily on iSchool institutions, this study argues that internationally renowned universities offer forward-looking models worth emulating. We therefore examine data visualization courses at QS Global Top 100 universities across four dimensions—prerequisite knowledge, teaching plans, course content, and assessment methods—to analyze their implementation and characteristics, providing insights for Chinese LIS departments. Since the core purpose of data visualization courses is to enhance students' data visualization literacy, course content should center on the literacy development process, using required core skills as the foundation while extending to non-core content for comprehensive competency development. K. Börner's DVL-FW process model articulates key steps in developing data visualization literacy and has been refined through over a decade of teaching practice at Indiana University, demonstrating practicality and representativeness [1]. Therefore, in analyzing course content, this study employs the DVL-FW process model to examine curriculum data from

QS Global Top 100 universities, offering references for core content development in Chinese LIS departments.

3.1 Research Objects and Methods

This study examines universities ranked in the 2023 QS World University Top 100, investigating their data visualization courses offered in 2022 or planned for 2023. The search focused on traditional credit-bearing courses for students organized by academic departments, excluding professional training programs and extracurricular library activities. Considering the diversity of course titles, search keywords primarily included "visualization" and its variants. Search approaches included: (1) university course catalog pages for identifying data visualization courses, and (2) site-wide searches to collect relevant data. The final sample comprised 53 universities offering 113 data visualization courses.

3.2 Course Overview

Country Distribution
The 113 data visualization courses are distributed across 12 countries, including the United States, United Kingdom, China, Australia, and Sweden [Figure 1: see original paper]. US institutions account for 22 universities with 66 courses; UK institutions represent 11 universities with 14 courses; and Chinese institutions comprise 6 universities with 12 courses. These three countries collectively account for 81.4% of all courses. The remaining 21 courses (18.6%) are distributed across Sweden, Japan, Switzerland, South Korea, Singapore, Canada, the Netherlands, and Denmark, with most countries having 1-2 institutions. Among the 27 US universities in the QS Top 100, 22 offer data visualization courses; among 17 UK universities, 11 offer such courses; and among 12 Chinese universities, 6 offer them, demonstrating strong commitment to data visualization literacy education and demand for talent in these countries.

Target Majors
The 113 courses serve 30 different majors, including Data Science, Geographic Information Systems, Journalism, Business Analytics, Cognitive Science, and Actuarial Science, spanning Architecture, Management, Computer Science, Business, Economics, Statistics, and Life Sciences. Courses include both required and elective options. Among 55 courses with available data, 26 are required and 29 are elective, targeting both undergraduate and graduate students. For example, the University of Chicago's Computer Science Department offers a "Data Visualization" course for Data Science undergraduates to understand visualization perception principles, methods, and applications, while UC Berkeley's School of Public Health requires a "Public Health Data Visualization" course for graduate students to learn graphic design theory and its application in communicating health data to diverse audiences.

4. Analysis of Data Visualization Courses

This analysis examines "how to teach" and "what to teach" in data visualization courses at 53 internationally renowned universities. Using web-based investigation, we collected valid datasets for 113 visualization courses: (1) prerequisite knowledge data for 33 courses, (2) teaching plan data for 17 courses, (3) course content data for 70 courses, and (4) assessment method data for 28 universities plus curriculum design data for 6 universities. Teaching plans are analyzed from course duration and teaching methods perspectives. Course content is categorized into six themes using the DVL-FW model and content analysis. Assessment methods and curriculum design are examined from four angles: general assessment approaches, basic curriculum design information, arrangements, and evaluation. Finally, we summarize the characteristics of data visualization course offerings.

4.1 Prerequisite Knowledge Analysis

Among 113 courses, 33 provide prerequisite information. Prerequisites ensure students possess essential foundational knowledge and skills for successful course participation. Analysis of these 33 courses reveals three main requirement categories: (1) Statistics, mathematics, data science, and computer science knowledge (required by 20 courses); (2) Programming knowledge and skills (required by 13 courses, typically at basic levels); and (3) Major-specific knowledge (required by 4 courses). For example, Lund University's "Data Visualization" requires a foundational statistics course, Duke University's "Advanced Data Visualization" requires "Foundations of Data Science," and Delft University of Technology's "Medical Visualization" requires basic programming knowledge. Major-specific prerequisites include Johns Hopkins University's "Map Design and Visualization" requiring GIS knowledge and its "Genomic Data Analysis and Visualization" requiring molecular biology and bioinformatics background, ensuring targeted and systematic curriculum design.

4.2 Teaching Plan Analysis

Seventeen courses from 53 universities provide detailed teaching plans , analyzed from course duration and teaching method perspectives.

Course Duration
Twelve of seventeen courses span 10 weeks or more. For instance, the University of Washington's "Data Visualization" runs 10 weeks, MIT's "Interactive Data Visualization" 14 weeks, Peking University's "Visualization and Visual Analytics" 16 weeks, and the University of Science and Technology of China's "Visualization Design and Development" 50 hours (30 theory, 20 practice), indicating that most universities allocate substantial time for knowledge absorption.

Teaching Methods
All seventeen courses combine theory and practice with supplementary activities including quizzes, assignments, exercises, readings, and expert lectures.

Theory instruction primarily uses traditional classroom teaching, while practice focuses on project-based design. MIT's "Interactive Data Visualization" allocates weeks 1-11 and 13 to theory (visual encoding, perception, interaction, frontiers) and weeks 12 and 14 to student visualization projects. Weekly readings and exercises match course themes—e.g., week 4 on "perception" requires students to design both correct and misleading visualizations using provided datasets to understand human perception in visualization. Peking University's "Introduction to Visualization and Visual Computing" uses 15 weeks for theory and 4 weeks for projects, with a midterm exam in week 7. The University of Wisconsin-Madison's 15-week course embeds four weekly tasks: pre-class readings, online discussions, design exercises, and learning surveys where students reflect on weekly content and self-assess understanding.

shows teaching plans for 17 courses, detailing weekly theory/practice distribution and supplementary methods across institutions including Carnegie Mellon, UCL, University of Chicago, University of Washington, MIT, University of Wisconsin-Madison, Peking University, University of Science and Technology of China, and Tokyo Institute of Technology.

4.3 Course Content Mapping Analysis Based on DVL-FW Process Model

Introduction of DVL-FW Process Model
For content analysis, we reference K. Börner's DVL-FW process model [1] and its interpretation by Chinese scholars Huo Chaoguang and Lu Xiaobin [2]. The DVL-FW model articulates six key stages in developing data visualization literacy [Figure 2: see original paper]: needs insight, data acquisition, data analysis, visualization, interaction deployment, and interpretation. Needs insight transforms real-world problems into data visualization problems through understanding user requirements. Data acquisition involves obtaining optimal datasets while ensuring quality and coverage. Data analysis includes preprocessing (outlier removal, cleaning) and transformation. Visualization comprises two aspects: (1) reference system selection (choosing appropriate forms like charts, tables, maps) and (2) data overlay design (selecting graphical symbols and variables such as points, lines, color, size, position). Interaction deployment includes static and dynamic interactions (e.g., zoom controls, hover, double-click) based on application scenarios. Interpretation presents visualization results to users to solve real-world problems. The model is cyclical, ensuring optimal results through iterative analysis, visualization, and interaction.

The DVL-FW model not only explains the literacy development process but also indicates pedagogical directions. We therefore categorize course content into six themes [Figure 3: see original paper] and map 70 courses accordingly. Based on Börner's framework and our research context, we established two mapping criteria: (1) Content elements belonging to these themes are counted accordingly (e.g., "infographics, graphs and networks, visual design principles, color theory" → "visualization"; "filtering, details (UI/UX)" → "interaction deployment";

"data storytelling skills" → "interpretation"). (2) Explicit descriptions with similar meanings to the six stages are directly mapped (e.g., "discussing data collection and storage in the penultimate week" → "data acquisition"; "teaching heuristics for different data analysis types" → "data analysis"; "exploring methods to make visualizations interactive" → "interaction deployment").

Course Content Mapping Results

As shown in [Figure 3: see original paper], themes appear with the following frequencies: needs insight (2 instances, 2.9%), data acquisition (17, 24.3%), data analysis (39, 55.7%), visualization (67, 95.7%; 3 courses with vague descriptions excluded), interaction deployment (33, 47.1%), and interpretation (19, 27.1%). While all six stages are covered, attention varies significantly.

The 70 courses emphasize data analysis, visualization, and interaction deployment (each >30 instances). Data analysis covers statistical and data science techniques for dataset processing, such as Peking University's week 2 focus on data abstraction and encoding, LSE's module on cleaning, transformation, and relational database models, and City University of Hong Kong's key emphasis on this theme. Visualization includes representation and graphics knowledge, such as MIT's weeks 4-5 coverage of graphical perception, color, SVG, symbols, and scales; Edinburgh University's techniques for geographic and temporal data; and UBC's weeks 2, 3, and 5 on representation methods, chart types, and color. Interaction deployment covers static and dynamic interaction skills, such as MIT's teaching of animation, filtering, data connections (enter, update, exit) using JavaScript, and EPFL's week 5 focus on interaction, filtering, and UI/UX.

However, needs insight, data acquisition, and interpretation receive insufficient attention. Only Johns Hopkins University's "Data Visualization" and University of Michigan's "Business Intelligence and Data" emphasize problem definition before data collection and visualization design. Data acquisition is often neglected because instructors typically provide datasets, with only 24.3% of courses covering this theme, including National Taiwan University's weeks 4-5 on data exploration and preparation, and Johns Hopkins University's "Image Processing and Data Visualization" teaching skills for acquiring data using VR headsets and haptic devices. Similarly, only 27.1% address interpretation, such as the University of Washington's and UNSW's coverage of visualization storytelling, and MIT's week 8 discussion of narrative forms, techniques, and technologies. Needs insight determines visualization direction, data acquisition affects dataset quality and is prerequisite for analysis, and interpretation bridges visualization solutions with real-world problems—all requiring equal emphasis.

Additionally, "tool learning, critical thinking, and ethics" emerged as important cross-cutting themes. Forty-four courses involve tool learning (programming languages and software), such as Chicago University's week 1 R language instruction, EPFL's 2-week JavaScript training, and Sydney University's week on Tableau. Six courses address critical thinking—evaluating visualization effectiveness, clarity, and truthfulness—such as Duke University's "Advanced Data

Visualization," Cornell's "Interactive Information Visualization," and UCL's "Data Visualization and GIS." Only Sydney University's "Data Visualization for Managers" includes ethics education on moral challenges. Thirteen courses also extend to real-world applications, such as Peking University's 3-week segment on applications in humanities, engineering, and data journalism, and Penn State's "Data Visualization for Business Decision-Making" exploring marketing, finance, and supply chain scenarios. Teaching these themes enriches data visualization literacy education, ensuring comprehensive competency development beyond core content.

4.4 Assessment Methods Analysis

Assessment data from 32 courses at 28 universities emphasize two dimensions: learning performance and personal quality development. Learning performance is evaluated through class discussions, quizzes (theory and programming), exercises, assignments, projects, and written reports. Personal quality development assesses teamwork and presentation skills. The University of Texas at Austin's "Data Storytelling" course exemplifies this balanced approach: discussions (10%), data presentation exercises (10%), data analysis assignments (30%), a visualization article (5%), storytelling exercises (5%), short presentations (5%), design exercises (5%), project reports (5%), and final project delivery and presentation (25%).

Curriculum Design as Assessment
Curriculum design requires students to build interactive visualization webpages or systems to solve specific problems through project-based work, effectively integrating theory and practice. Analysis of six universities with detailed design data reveals three common features: substantial weight (all >30% of total grade), extended duration (four courses $ $6 weeks), and teamwork. For example, Peking University's "Visualization and Visual Analytics" assigns 55% weight to the project, with teams of 3-5 students working over multiple weeks, checking progress at specific milestones.

The six universities' design processes follow three phases: (1) early-stage team formation, topic selection, dataset choice, and preliminary proposals; (2) mid-stage implementation or design report writing; and (3) final-stage presentations and delivery. MIT's "Interactive Data Visualization" requires project proposals with team member names, problem statements, and dataset descriptions; mid-stage 5-minute video presentations demonstrating current visualizations, prototypes, design strategies, and Q&A; and final delivery including a 1-minute trailer, 2-4 page conference-style paper, project materials summary, detailed code documentation, and optional exhibition participation. Peking University's process similarly requires initial development reports analyzing data types, dimensions, methods, and preliminary designs; mid-stage detailed visualization and interaction design reports; and final delivery including a comprehensive project report, functional system with source code, 1-minute demo video, poster, and presentation slides.

Curriculum Design Evaluation

Evaluation criteria from three universities all include "application of visualization knowledge and skills," aligning with course objectives while offering diverse perspectives. MIT emphasizes methods, design strategies, skill proficiency, novelty, and problem-solving capability. HKUST focuses on writing skills and analytical depth. UBC assesses technical difficulty, implementation quality, practicality, writing, and teamwork. These multifaceted evaluation systems provide valuable references.

5.1 High Recognition of Data Visualization Courses in Leading Universities

In today's complex data environment, data visualization literacy is an essential skill. Among QS Top 100 universities, 53 offer 113 data visualization courses. Thirty-four percent (18 universities) offer three or more courses; two have established data visualization majors; 26 courses are required; and instruction spans nearly 30 disciplines at both undergraduate and graduate levels. This demonstrates that over half of leading universities recognize the importance of data visualization education, actively implementing comprehensive curricula to develop integrated competencies.

5.2 Strong Interdisciplinary Characteristics

Among 80 courses with explicit major information, 28 target Data Science, Data Analytics, and Big Data majors—35% of all courses at 53 universities, such as Chicago University's "Data Visualization" for Data Science majors, Sungkyunkwan University's "Data Visualization" for Big Data majors, and Sydney University's "Data Visualization for Managers" for Business Analytics majors. The remaining 52 courses span nearly 30 disciplines including Human-Computer Interaction, Global Policy Studies, Urban Planning, Nursing, and GIS. These courses take two forms: (1) traditional courses focusing on data visualization expertise, such as HKU's "Visualization and Visual Analytics" for Engineering and UNSW's "Data Visualization and Communication" for Business; and (2) innovative interdisciplinary courses integrating domain knowledge, such as USTC's "Medical Imaging and Information Visualization Technology" combining medical imaging with visualization techniques, and UC Berkeley's "Public Health Data Visualization" focusing on health data applications. This demonstrates clear interdisciplinary characteristics and discipline-specific adaptation.

5.3 Integration of Theory and Practice

Among 17 universities with detailed teaching plans, 11 combine theory and practice with supplementary methods including quizzes, assignments, exercises, readings, and expert lectures. MIT's "Interactive Data Visualization" includes 12 theory weeks and 2 practice weeks plus readings, assignments, lectures, and demonstrations. The University of Washington's course includes 9 theory weeks, 1 practice week, and five supplementary activities. USTC's "Visualization Design and Development" allocates 30 theory hours and 20 practice hours covering all six DVL-FW themes. Sydney University's "Data Visualization Analytics" addresses five themes, while UBC's "Information Visualization" covers three. Both extend to tool learning, critical thinking, ethics, and real-world applications. Project-based curriculum design, spanning 4-9 weeks, enables flexible application of theory to solve visualization problems, as seen in the University of Washington's process from dataset selection through prototype design to final interactive webpage delivery, encompassing theoretical application, technical challenges, design decisions, and teamwork.

5.4 Emerging Trend Toward Specialized Data Visualization Degree Programs

Two QS Top 100 universities have established data visualization majors: the University of Warwick and Penn State University . Both share two characteristics: (1) interdisciplinary positioning—Warwick's program is developed by its Centre for Interdisciplinary Methodologies (CIM) [17], while Penn State offers it as a minor accessible to interested students from any major; and (2) multidisciplinary curricula integrating psychology, design, programming, and statistics.

Unique features distinguish the two programs. Warwick's master's degree is more comprehensive and focused, emphasizing real-world applications through extensive case studies and project-based learning. Penn State's undergraduate minor prioritizes foundational theory with courses like "Introduction to Data Analysis," "Business Analytics," and "Programming Fundamentals."

6.1 Designing Core Content Using the DVL-FW Process Model

The DVL-FW model's six stages are interdependent and indispensable. However, leading universities overemphasize visualization design while neglecting the initial "needs insight" stage—focusing on "how to create" rather than "why create." Only Johns Hopkins' "Data Visualization" and Michigan's "Business Intelligence and Data Visualization" emphasize problem definition before data collection. Chinese LIS departments should ensure comprehensive coverage of all core stages, particularly needs insight, while cultivating cyclical thinking that treats visualization design as an iterative process for optimal solutions.

6.2 Emphasizing Auxiliary Skills: Tools, Critical Thinking, and Ethics

Programming knowledge is a key prerequisite in international courses, with many universities dedicating specific sessions to visualization software and languages (JavaScript, Tableau, GIS, Python, Illustrator, D3, web development). Since data visualization builds upon data mining, analysis, and AI technologies [2], Chinese LIS departments should strengthen programming and software instruction to enhance innovation while emphasizing critical thinking, ethics, and practical application to develop well-rounded professionals.

6.3 Balancing Theory and Practice Through Project-Based Instruction

As an application-oriented field, data visualization education must connect with student learning and societal needs. Theory-practice integration is essential, supplemented by exercises, discussions, group projects, readings, and presentations. MIT's "Interactive Visualization" requires pre-class readings with platform-based commentary, fostering critical analysis. Curriculum design is an effective assessment method providing systematic learning environments. While international universities typically use "provided dataset—team collaboration—presentation" models, Chinese departments could innovate by integrating competitions, real-world data scenarios, and gamification. Evaluation should incorporate problem-solving, teamwork, and analytical thinking for holistic development.

6.4 Promoting Interdisciplinary Course Offerings

Data visualization is applicable across multiple domains and should be positioned as an interdisciplinary course empowering various disciplines, not just LIS departments. Leading universities have integrated data visualization into nearly 30 disciplines, ensuring effective fusion of domain and visualization knowledge, such as UC Berkeley's health data visualization and UCL's "Sensor Data Visualization" for AR and IoT applications. Chinese LIS departments should advocate for expanded interdisciplinary offerings to cultivate visualization-literate talent across disciplines.

6.5 Establishing Data Visualization Majors or Minors

Warwick and Penn State offer data visualization majors for graduate and undergraduate students, combining psychology, design, programming, and statistics in both major and minor formats. This allows students to pursue visualization skills proactively based on interest. To cultivate domestic talent, Chinese LIS departments should consider establishing undergraduate or graduate majors/minors in data visualization, encouraging cross-departmental implementation and developing comprehensive curricula integrating multidisciplinary knowledge.

Driven by rapidly evolving big data environments and societal demand for visualization talent, data visualization literacy education represents a new growth area for library and information institutions. Chinese LIS departments should seize this opportunity, learning from globally representative best practices to implement data visualization education. This study has limitations, including the QS Top 100 sample scope and potential variations across disciplines, which warrant further research.

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Note: Figure translations are in progress. See original paper for figures.