

KNO-018 · Images, Diagrams and Visualisation

KNO · Ways of Knowing

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Ways of Knowing

Epistemic profile: Current scientific interpretation **Licence at publication:** All Rights Reserved

Article Abstract

Scientific images, diagrams and graphs can make patterns visible that are difficult to express in prose, but what exactly happens when data are turned into a visual display? This article examines diagrams, graphical encodings, scientific images and visualisation pipelines as related but distinct tools. It asks how spatial arrangement changes cognitive work, how perceptual channels affect quantitative judgement, how scale, framing and colour influence interpretation, and how acquisition and processing stand between a physical system and the pixels a reader sees. It also asks when alternative views reveal dependence on arbitrary choices, when processing clarifies rather than distorts, and what provenance is needed to make a figure auditable. The focus is not on whether visualisation is useful, but on which transformations a reader must be able to reconstruct before a visual pattern can function as evidence.

In 60 Seconds

A visual display can reduce cognitive work because spatial relations can make patterns explicit that prose leaves implicit. But visual channels differ in precision: position on a common scale is generally decoded more accurately than area or angle, and colour scales can create false boundaries or unequal emphasis. Similar summary statistics can conceal very different data structures, which is why plots and numerical summaries complement one another. A graph is still a transformation, not raw reality. Variables, scales, binning, aggregation, projection and framing determine what becomes visible. Scientific images add acquisition, reconstruction, filtering, segmentation and display conversion between the physical system and the published pixels. Processing can reveal useful structure, but it can also erase information or create misleading appearances if choices are hidden. An auditable figure therefore makes source data, transformations, encodings and important omissions inspectable, and uses alternative views when conclusions depend strongly on presentation choices and audiences.

Why This Question Matters

Modern science relies on visual intermediates: microscope images, maps, spectra, simulations, network diagrams, heat maps and statistical plots. A figure may be the first place a researcher sees an outlier, batch effect or nonlinear relation. That makes visualisation part of inquiry, not merely presentation. The same power creates risk: a display can exaggerate weak differences, hide extremes or turn processing decisions into apparently natural features. Treating visualisation as an epistemic instrument makes its transformations subject to the same scrutiny as measurements and models.

1. A Diagram Can Change the Work Required

Larkin and Simon showed that informationally equivalent representations can differ in computational efficiency: a spatial diagram may make relations explicit that a sentential description leaves to be derived [1]. This does not mean diagrams are universally superior. Their advantage depends on the task and on which relations the representation makes easy to inspect.

Where That Leaves Us

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2. Seeing Is Also Decoding

Graphs encode data into visual channels. Cleveland and McGill experimentally studied how accurately viewers decode elementary graphical encodings, establishing that the choice of channel affects quantitative judgement [2]. A visualisation therefore has a perceptual error structure as well as a statistical one.

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3. Summary Numbers Can Hide Structure

Anscombe constructed datasets with nearly identical conventional summary statistics but strikingly different scatterplots [3]. The lesson is not that plots replace statistics. It is that different representations expose different properties, so numerical and visual summaries should be treated as complementary checks.

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4. Every View Has a Task

Munzner's framework separates data abstraction, task abstraction, visual encoding and validation [4]. Ware similarly links display design to properties of human perception [5]. A figure is not simply 'good' in the abstract: it is good or bad for a specified question, audience, data type and decision.

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Munzner's framework separates data abstraction, task abstraction, visual encoding and validation [4]. A figure is not simply 'good' in the abstract: it is good or bad for a specified question, audience, data type and decision. The next section examines the proposition that scale and framing are part of the claim.

5. Scale and Framing Are Part of the Claim

Axes, limits, bin widths, aggregation and normalisation determine what a viewer can see. Changing them may be legitimate, but it changes the representation. The epistemic requirement is not to freeze one universal view; it is to disclose transformations that materially affect interpretation and to inspect plausible alternatives when conclusions depend on them.

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6. Colour Is Not a Neutral Label

Colour can separate classes and add dimensions, but hue has no universal quantitative ordering. Wong warned specifically that rainbow schemes are problematic for ordered values [6]. Crameri, Shephard and Heron showed that uneven colour gradients can distort apparent structure and can be inaccessible to readers with colour-vision deficiencies [7]. Modern perceptually designed scales improve this, but no palette removes the need to match encoding to task.

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7. An Image Is Data Plus a Rendering Pipeline

A microscopy image is not identical to the specimen. Acquisition settings, reconstruction, intensity scaling, filtering and display conversion stand between the physical system and the published pixels. Rossner and Yamada emphasised that digital manipulation can cross from legitimate adjustment into inappropriate alteration of the original data [8]. The key distinction is not 'processed versus unprocessed' but whether processing is scientifically justified, consistently applied where required, preserved, and disclosed.

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8. Processing Can Reveal and Conceal

The community-developed microscopy checklists, published online in 2023 and issued in Nature Methods in 2024, stress that image-processing and image-analysis workflows mathematically transform image data and should be transparently documented [9]. Adjustments to intensity range, non-linear contrast, filtering, restoration, segmentation or machine-learning steps can improve interpretability, but they can also remove information or generate misleading appearances. Raw or minimally processed data and workflow provenance therefore matter.

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The community-developed microscopy checklists, published online in 2023 and issued in Nature Methods in 2024, stress that image-processing and image-analysis workflows mathematically transform image data and should be transparently documented [9]. Raw or minimally processed data and workflow provenance therefore matter. The next section examines the proposition that a visual pattern is not yet an explanation.

9. A Visual Pattern Is Not Yet an Explanation

A cluster, gradient or apparent boundary in a plot can be a clue. It does not by itself identify mechanism or cause. The display may reflect the underlying system, preprocessing, sampling, projection, smoothing or the encoding itself. Visualisation generates and tests questions; causal interpretation still needs the evidential machinery developed in KNO-014 and KNO-016.

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10. Multiple Views Are a Form of Stress Test

Because every encoding privileges some relations, comparing views can reveal dependence on arbitrary choices. A scatterplot, residual plot, histogram and tabular summary can interrogate different aspects of the same dataset [3,4]. Multiple views do not create independent evidence if they derive from the same observations; that final statement is a declared synthesis of this article rather than a claim directly established by those sources.

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Because every encoding privileges some relations, comparing views can reveal dependence on arbitrary choices. Multiple views do not create independent evidence if they derive from the same observations; that final statement is a declared synthesis of this article rather than a claim directly established by those sources. The next section examines the proposition that clarity is not the same as truth.

11. Clarity Is Not the Same as Truth

A clear figure can present a wrong model beautifully. A cluttered figure can contain valid evidence badly. Perceptual effectiveness, statistical validity and scientific interpretation are distinct dimensions. Good visualisation aligns them without treating any one as a substitute for the others.

Where That Leaves Us

A clear figure can present a wrong model beautifully. A cluttered figure can contain valid evidence badly. Perceptual effectiveness, statistical validity and scientific interpretation are distinct dimensions. Good visualisation aligns them without treating any one as a substitute for the others. The next section asks what makes a figure auditable rather than merely persuasive.

12. The Auditable Figure

An auditable scientific visualisation lets a reader identify the source data, transformations, visual encodings and important omissions. For scientific images, that includes acquisition and processing provenance; for graphs, it includes scales, aggregation and uncertainty where relevant [8,9]. Reproducibility of the rendering pipeline is not proof that the scientific claim is true, but opacity about the pipeline makes the claim harder to evaluate.

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Claims

C01. Diagrammatic and sentential representations can be informationally equivalent yet differ in computational efficiency for specific tasks. [1]

C02. Graphical encodings differ in perceptual decoding accuracy. [2]

C03. Similar summary statistics can coexist with substantially different data structures visible in plots. [3]

C04. Visualisation design should be evaluated relative to data, task, encoding and validation level. [4]

C05. Perceptual properties constrain effective display design. [5]

C06. Hue is a problematic sole channel for ordered quantitative magnitude, and rainbow maps can mislead. [6,7]

C07. Colour-map accessibility and perceptual uniformity are scientific communication issues, not merely aesthetic ones. [7]

C08. Digital scientific-image manipulation can alter evidential meaning and must be controlled. [8]

C09. Image-processing and image-analysis workflows transform numerical image data and require transparent reporting. [9]

C10. Legitimate image processing does not make the displayed image identical to the unprocessed acquisition. [8,9]

C11. Multiple visual views can expose structure or assumptions hidden by a single representation, without becoming independent evidence. **Declared synthesis; sources 3 and 4 provide context, not direct support for the independence clause.**

C12. Reproducible rendering improves auditability but does not itself establish the truth of the scientific interpretation. **Declared synthesis; sources 4, 8 and 9 provide context on validation, integrity and reporting, not direct support for the truth-status clause.**

Boundary Note

KNO-018 concerns visual representation as a method of knowing. It does not replace KNO-006 on cartography, KNO-013 on models, KNO-014 on causal identification, KNO-015 on probability/uncertainty, or KNO-019 on data tables and record structures. It also does not claim that one visual grammar is universally optimal.

What We Know, and How

Visual representations transform data into spatial and perceptual encodings. Those choices affect what patterns are easy to detect, how accurately quantities are decoded and which aspects of acquisition or processing remain visible to the reader.

What We Still Don't Know

No single visual encoding is optimal for every task, audience or dataset, and an attractive or reproducible rendering does not establish the correctness of the scientific interpretation. Important structure can remain hidden outside the chosen view.

What Could Change Our Minds

Interpretation should change if alternative scales, encodings, processing steps or views remove the apparent pattern, if provenance reveals unreported transformations, or if a visual feature cannot be reproduced from the stated source data and pipeline.

If You Remember Only One Thing

A scientific figure is evidence only when its transformation from source data to display is appropriate, inspectable and open to reconstruction.

Related Articles

- KNO-006 · Maps and Spatial Representation
- KNO-013 · Models, Maps and Reality
- KNO-014 · Causality and Correlation
- KNO-019 · Data, Tables and Records

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