Diagrams as Vehicles of Scientific Reasoning
10-12 April 2015
ABSTRACTS

Mary Hegarty, Keynote Speaker
University of California, Santa Barbara, Psychology

The Power of Diagrams in Science and the Challenges of Diagrams in Science Education

Scientists are facile in using a range of different diagrams of spatial phenomena that vary in their dimensionality, abstraction, and spatial perspective. However science students often have difficulty understanding and reasoning with disciplinary diagrams. I will review studies of how people understand and reason with diagrams in the domains of mechanics, anatomy, and chemistry. These studies illustrate the power of diagrammatic representations for experts but also the challenges that beginning science students encounter in mastering these representations. I will suggest ways of using virtual and physical models to fostering students' mastery of diagrammatic representations and reasoning.

Christian Schunn, Keynote Speaker
University of Pittsburgh, Psychology & Learning Research and Development Center

When (and Why) Do Mathematical Representations Help Students Think Scientifically?

In science, diagrams often serve as the bridge between empirical and theoretical, what was found and what is thought to be. Mathematical transformations and representations play a central, but perhaps partially hidden, role in this bridge. This mathematics can be approached in very transactional terms, necessary evils of little theoretical value to conceptual reasoning. Or the mathematics can be approached in deeply theoretical terms, as central theoretical commitments about objects and mechanisms. I present data arguing for the strong benefits of the latter approach in helping high school biology students come to understand underlying phenomena and solve complex problems of genetic inheritance, which includes the productive and flexible use of situation models, process diagrams, and data representations.

Andrea Woody, Keynote Speaker
University of Washington, Philosophy
The Mediating Role of Diagrammatic Representation in Chemical Reasoning

In this talk I will explore the active role of diagrammatic representation in mediating between qualitative and quantitative conceptual resources in chemistry, while also, sometimes simultaneously, integrating molecular (microscopic) and molar (macroscopic) aspects of chemical phenomena. Both sorts of navigation are essential to the reasoning required of modern chemical theory. After providing an initial characterization of diagrammatic representation that aims to highlight its distinctive representational features, I will consider four arenas in which diagrams play an essential role in contemporary chemical practice: (1) molecular orbital diagrams in quantum chemistry, (2) reaction mechanism diagrams in organic chemistry, (3) the periodic table, and (4) graphical abstracts in chemical publication. In each case, I will attempt to highlight the value added by diagrammatic representation. The underlying aim of my discussion is to grapple with how best to incorporate such value into philosophical analyses of scientific reasoning and representation.

Yin Chung Au
University College London, Department of Science and Technology Studies
Synthesizing Heterogeneity: A Quantitative Study of Diagrams in Apoptosis Research, 1980-2005

This is a case study of diagrams in one specialty of biological mechanism research (apoptosis), revealing the crucial role of diagrams in developing mechanistic explanations for biological phenomena. The quantitative part shows the prevalence of two themes of diagrams: object and mechanism. Their relative changes in coverage suggest a shift in the focus of practice from manipulating macromolecules to inter-field interactions of heterogeneous perspectives. The qualitative part argues for two points. Firstly, diagrams embody the interactive and integrative features of biological mechanism research. Secondly, the relationships amongst heterogeneous component signs are central to generating meanings of mechanism diagrams as wholes. Mechanism diagrams are the media for constantly communicating (1) the researcher with the wider community, and (2) the same researcher between one's different stages of

model development. Meanwhile, they mediate between the formation of ideas and the researcher's intervention in the mechanisms of interest.

Justin Humphreys
New School for Social Research, Philosophy
Abstraction and Diagrammatic Reasoning in Aristotle's Philosophy of Geometry

How can the geometer make universal inferences from a particular diagram? Aristotle answers this question by invoking the concept of abstraction, a "taking away" of certain features of a particular. This operation is usually interpreted either psychologically, as a mental act of removing properties from a magnitude in thought, or linguistically, as the elimination of predicates from a grammatical subject. I raise objections to both views, and present an alternative interpretation based on the assumption that diagrams play a constitutive role in ancient mathematical practice. On my reading, to abstract is to vary an inequality or another diagrammatically represented relation to produce a more general inference from a given diagram. This supports an understanding of Aristotle's theory of abstraction as part of a broader consequentialist philosophy of mathematics that is neither psychological nor ontological but is meant to show how geometry must be a species of demonstrative science.

John Huss
The University of Akron, Philosophy
Diagrammatic Reasoning in Paleontology: Two Case Studies

In paleontology, processes are often inferred from patterns. This requires evaluating historical counterfactuals, which paleontologists can explore using diagrams as templates. Here I present two historical case studies. One case involves a computer simulation of evolution. Representing those simulation results diagrammatically masked scaling problems that would have been revealed had the results been presented numerically. The second case used an empirically derived diagram representing fossil occurrences of ammonites in a geologic column to pose a counterfactual: if we were to impose a sudden mass extinction at point X in the geologic column, would the observed pattern look sudden, stepwise, or gradual? These cases suggest that diagrammatic reasoning

in paleontology is a heuristic that adapts inferential problems to a "visual language" familiar to paleontologists. Yet the assumptions underlying representational choices can influence the inferences drawn in ways that compromise the validity of the inference.

Yoichi Ishida
Ohio University, Philosophy
Visual Thinking in Genetics: A Case of Genetic Maps in Seymour Benzer's Research on Genetic Fine Structure

Abstract: TBD

Allen Janis
University of Pittsburgh, Physics and Astronomy
Diagrams in Physics

Diagrams are ubiquitous in physics, from the time a student begins to learn Newtonian mechanics to the time a research scientist attacks a problem in particle physics or general relativity. I shall begin with examples drawn from the elementary classroom, and then discuss the space-time diagrams of special relativity. Next, I shall discuss the use of Feynman diagrams in quantum electrodynamics and particle physics. My final example will be the use of Penrose diagrams in the study of asymptotically flat space-times in general relativity. In a Penrose diagram, space-time is represented with infinity at a finite distance. This is achieved by using a metric that is conformal to the physical metric; i.e., the two metrics differ by an overall scalar factor. All of these concepts will be explicated.

Miles MacLeod (presenting) & Nancy J. Nersessian
University of Helsinki, Centre for Excellence in the Philosophy of the Social Sciences
The Cognitive Role of Diagrams in Interdisciplinary Model-building: The case of molecular pathway diagrams

Philosophers are paying increasing attention to the importance of diagrams in scientific reasoning and argumentation, such as their role in explanation. We have as yet only a few studies in philosophy of science of the intensive roles that

diagrams play in the ability of researchers to think through problems and build good scientific models (see Gooding, 2006; Nersessian, 2008; Sheredos et al., 2013; Jones and Wolkenhauer, 2012; Bechtel and Abrahamsen, 2012). Diagrams in this context provide affordances for problem solving by representing partial aspects of a phenomenon in a cognitively accessible and manipulable way. In interdisciplinary contexts even more weight can be placed on diagrams since they often are the "boundary objects" through which communication and collaboration take place (Star and Griesemer, 1989). In this paper we further investigation of the important cognitive roles that molecular pathway diagrams play in the model-building process in integrative systems biology. We suggest that the same reasons that explain why a diagram, such as a pathway diagram, might be useful for building models of complex phenomena can also help to understand why that diagram is useful for interdisciplinary communication and collaboration. Diagrams used in the model-building process support basic cognitive reasoning mechanisms that are shared across disciplinary boundaries and translatable into more technical disciplinary language and thought.

Iulia Mihai
University of Ghent, Sarton Centre for History of Science
Diagrams and Problem Solving: Taylor and Euler on the vibrating string

In this paper I distinguish two classes of diagrams used by Brook Taylor (1715) and Leonhard Euler (1748) in solving the problem of the vibrating string. I show that some epistemic functions assigned within the structure of the two proofs to diagrams are satisfied differently by the two classes. Only one class of diagrams, depicting the string as an idealized mechanical system, has a preliminary heuristic function. The reading of these diagrams is embedded in the mathematical context of each proof, which significantly changes from Taylor to Euler. Both classes share the representation function for the output, i.e. the model of the motion of the string, but I argue that they themselves are not the model. Diagrams are part of mechanical problem-solving and the way in which they satisfy various epistemic functions shows differences in problem-solving styles.

Laura Perini
Pomona College, Philosophy
Evidential Reasoning at the Limits of Depiction

Abstract: TBD

Greg Priest
Stanford University, History

Charles Darwin's "Tree of Life" Diagram as a Model of Evolutionary Processes

In 1837, Charles Darwin wrote in a notebook that "organized beings represent a tree, irregularly branched" and sketched a simple drawing of a tree to illustrate the idea. From this seed was to grow the only illustration included in the *Origin*—the "tree of life" diagram. A number of scholars have explored how Darwin used the tree of life metaphor, and its associated diagram, to explain and persuade. But a rhetorical analysis does not exhaust the role Darwin's tree diagrams played in the development of his theory. Darwin deployed the tree diagram as a model of evolutionary processes, as a tool to enable him to think through a number of the most difficult questions raised by his theory. By exploring this aspect of Darwin's tree diagram, we can better understand central aspects of his thought, and gain insight into how diagrams can contribute to the development of scientific theories.

Henk W. de Regt
VU University Amsterdam, Philosophy

Feynman Diagrams as Tools for Scientific Understanding

This paper offers an account of the relation between visualization and understanding, and supports it with concrete examples of the use of visualization in twentieth-century theoretical physics, with a focus on the development of quantum field theory in the years since World War II. Its main thesis is that visualization is an effective tool for achieving scientific understanding, but, contrary to what some scientists and philosophers have suggested, it is not a necessary condition for understanding. To be sure, the popularity and successes of Feynman's diagrammatic approach in quantum field theory underscores the power of visualization, but does not invalidate the abstract approach of Schwinger and Tomonaga. Instead, the existence of alternative approaches illustrates the variation in conceptual tools that may be employed for obtaining understanding.

Ben Sheredos
University of California, San Diego, Philosophy

Six Pictures in Supplemental are Worth More than 1000 Words in Main Text: Analysis of Circadian Biologists' Publication Practices

I provide a case study of how a team of biologists (through 11 drafts, over 4 months) crafted an original research article. I aim to foster discussion regarding two features of scientists' graphical practices ("GPs") revealed here, but which have previously gone understudied. First, while the article's data-graphics were settled early, and were largely produced by individuals working at the bench, in contrast the article's central mechanism diagram developed more gradually, arising through a collaborative decision-making process. Second, in response to reviewer comments (and to meet page-limits) the authors radically revised the penultimate draft, deleting large portions of prose in main text, and moving many graphics' panels out of the main text and into "supplementary information." Both points highlight the importance of social influences (intra-laboratory and extra-lab) on GPs, and set us the task of incorporating these influences into any adequate account of how scientists reason with diagrams.

Thomas F. Shipley (presenting) & Kristin Gagnier
Temple University, Psychology

Using Sketching to Support Students in Developing Rich 3D Representations from STEM Diagrams

Science, Technology, Engineering and Mathematics (STEM) disciplines commonly illustrate 3D relationships in diagrams, yet these are often challenging for students. We explore a new approach to improving student understanding of diagrams that convey complex 3D relations. Our approach is based on students generating their own *predictive* diagrams. Participants' comprehension of 3D spatial diagrams was measured by pre and post tests that assessed skill in selecting the correct 2D slice through 3D geologic block diagrams. Generating sketches that predicted the internal structure of a model led to greater improvement in diagram understanding than visualizing the interior of the model without sketching, or sketching the model without attempting to predict unseen spatial relations. Results suggest that generating a predictive diagram facilitates students' abilities to make inferences about spatial relationships in diagrams. Implications for use of sketching in supporting STEM learning is discussed.

Amir Teicher
Weizmann Institute of Science, Molecular Cell Biology
Broken Lines: Visualizing Human Differences in Twentieth-century Anthropology and Psychology

In 1907, German anthropologist Theodor Mollison invented a unique method for racial differentiation, called 'deviation curves'. By transforming anthropometric data matrices into graphs, Mollison's method enabled comparing simultaneously a large number of physical attributes of individuals and groups. However, the construction of deviation curves had been highly desultory, and their interpretation had been prone to various visual misjudgments. Albeit their methodological shortcomings, deviation curves became very popular among racial anthropologists and psychologists. By giving separate measurements a consolidated visual form, they substantiated the idea that the attributes of certain social groups were part of distinct racial compounds. Deviation curves thus reinforced racial suppositions, in face of severe criticism on the ontological reality of race itself. Moreover, deviation curves emphasized the biological singularity of disadvantaged human groups – Jews, Africans, and also women – and of their divergence from ideologically-defined physical norms.

Ryan D. Tweney
Bowling Green State University, Psychology
Maxwell's Use of Diagrams: The Interplay of Mathematics and Visualization

James Clerk Maxwell's Treatise on Electricity and Magnetism (1873) contains over 150 diagrammatic illustrations. While many of these are conventional (e.g., data plots, illustrations of apparatus), some are representations of the visual and geometrical models that Maxwell used in developing his theory of the electromagnetic field. In the presentation, a variety of such diagrams will be shown and their relation to his mathematical representations of the field discussed. It will be argued that the diagrams are essential parts of his model-based reasoning, parts that can be understood as cognitive manifestations of his thinking. As cognitive supplements to his mathematical representations, they

clarify both the content of his model and the cognitive underpinnings, which enabled his mathematical physics.