Diversity, Thinking Styles, and Infographics

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ABSTRACT

This paper examines a fundamental issue, the way a scientist thinks, and considers whether thinking styles are a factor in determining who participates successfully in science. The paper presents a framework for discussion of diversity in thinking styles. Academic tradition supports one style, while feminist literature advocates the adoption of another. The paper scrutinizes thinking processes in science, and questions assumptions by both scientists and non-scientists about the relative merits of the different styles. The analysis shows that diversity supports merit in science. A new concept, infographics, is introduced to facilitate the examination of information trends in STEM and the implications of different thinking styles. The infographic forecast provides the strongest argument for diversity in science.

The results of the present analysis are general principles for education and policy entirely consistent with those already being applied in specific sectors by informed advocates for women's participation. The added value of the present approach is: a) it counters the perceived tension between granting access and maintaining quality in STEM; b) it provides guidance for efforts to open 'alternate paths' to STEM; c) it helps to explain and learn from the variations in women's participation in different STEM sectors.

Keywords: diversity, science, mathematics, epistemology.

INTRODUCTION

After decades of active promotion of women in science, technology, engineering, and mathematics (STEM), the low ratios of women in some sectors and institutions persist, or are slipping. The statistics for Canada are similar to those for the United States and several European countries, e.g. approximate ratio of women in undergraduate engineering programs, 20%, in computer science 15%. While advocates for increased women's participation have worked steadily and seen little change overall, leaders and managers working for change have also been frustrated by the ephemeral results of promotion programs. These circumstances indicate the need for a fresh analysis of the concepts and processes which lead individuals to successful participation in STEM. The objective is not merely to avoid further slippage of the participation of women, but to substantially advance women's participation. An anticipated result is that measures which attract and retain more women in STEM will also facilitate the participation of men.

The role of the university in the process which leads to participation in STEM was analysed in [1]. The university acts as a feedback loop, strongly influencing the process. That paper uses the pipeline concept to show that if there is even a small gender bias in diversion ratios, then a gender minority in the retained group will persist indefinitely. Finally, the paper shows why the university is among the most traditional of institutions in western/northern society, and hence slowest to change of its own accord.

The influence of the academic tradition on a particular subject, mathematics, was explored in [2]. In the western/northern academic tradition, a particular style of communication and teaching has become associated with rigour, and hence merit, in mathematics. The result is that expression has obscured substance. Many people believe, incorrectly, that academic mathematics fairly represents mathematics.

This paper focuses on processes in science, including mathematics. Engineering and technology are strongly influenced by science but the culture is sufficiently different to confuse the present argument. We examine a fundamental process, the manner in which a scientist thinks, and the possibility of gender differences. We also consider whether thinking style is a factor in determining who participates successfully in science. The analysis shows that diversity supports good science. The paper concludes with a brief examination of information trends in STEM and the corresponding evolution of scientific thinking styles. The information forecast provides the strongest argument for diversity in science.

THINKING AND GENDER DIFFERENCES

An individual's thinking style affects communication, information handling, problem solving, learning, and teaching. A discussion of either thinking styles or gender differences must begin with a caution: segmentation is simplification. Characteristics are distributed, groups overlap, and people may think in different ways according to training, experience, and circumstance. However, defining two distinct thinking styles is a simplification which provides a framework for a discussion of diversity.

A hierarchical thinking style connects information in an axiomatic progression (Figure 1). Also called canonical, [3], and in this paper axiomatic, it is characteristic of pure mathematics, structured programming, and highly specialized fields. At the other end of the spectrum, the relational thinking style considers more pieces of information simultaneously, and looks for connections following identified patterns (Figure 2a). It is often associated with intuition and is characteristic of applied mathematics, object oriented programming, and interdisciplinary fields.

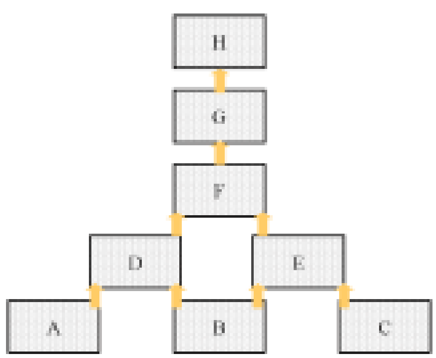

Figure 1: Axiomatic thinking process.

Both styles use logical connections between the elements. The difference between the two styles is not in the application of logic but in the order of making the connections. While we commonly refer to the process represented in Figure 1 as a logical argument, it is actually an axiomatic argument. Furthermore, Figure 2b illustrates the process of intuition, that is the consideration of multiple logical connections before identifying a logical path from the initial information to the conclusion.

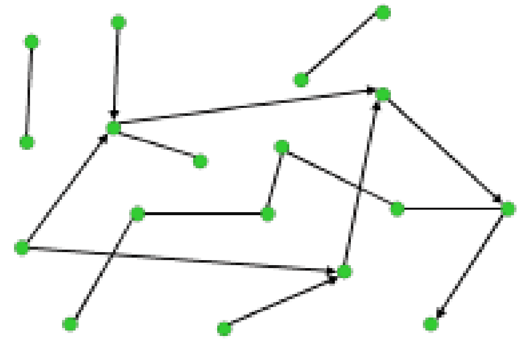

Figure 2a: Relational thinking process.

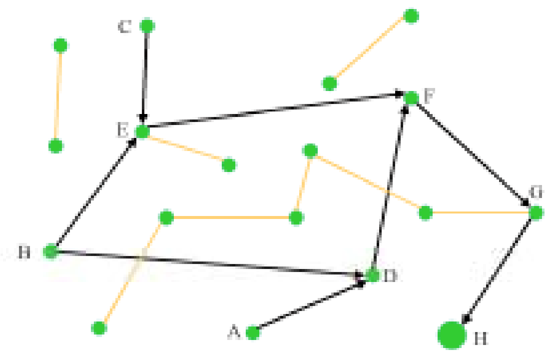

Figure 2b: Logical path in relational thinking.

There is considerable evidence in academic as well as popular psychology literature of gender differences in communication and learning styles, pointing to differences in underlying thinking styles. Gender differences in thinking styles are more difficult to quantify, because of differences in contexts, tests, and dimensions, and because thinking develops with age. Kolb's two-dimensional description with four learning style quadrants [4] is used by many researchers for adult subjects. The axiomatic-relational axis maps onto Kolb's plane with the axiomatic direction in the assimilator quadrant and the relational direction in the converger quadrant (Figure 3). With this mapping, two recent studies which considered gender [5, 6] show that, relatively, the styles of men are distributed towards the axiomatic direction and the styles of women are distributed towards the relational direction. Closer examination reveals a less anticipated result: only a small minority of either men or women could be classified as strongly axiomatic: in fact most women and most men are relational.

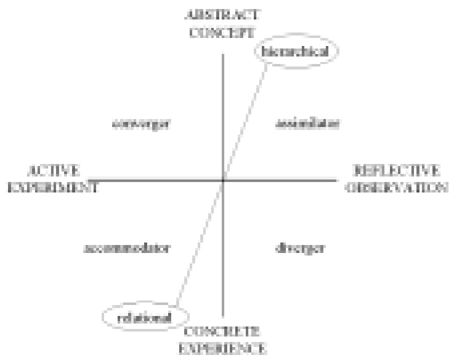

Figure 3: Thinking styles mapped onto the plane of Kolb's learning styles

THE SCIENTIFIC PROCESS

There are three stages to the scientific process: discovery, legitimacy, and validity. In the complex world of science, the stages may be executed by different people at non-sequential times. For the purpose of explaining them it is useful to think of a single person developing a simple scientific concept.

The first stage is discovery: the scientist acquires a concept through observation, deduction, hunch, hoax, hallucination, or some other process. At the second stage, legitimacy, most concepts terminate. For the concept to advance, the scientist must convince herself that it has merit and is likely to be valid. Her manner of knowing this (the epistemology) depends on her training, experience, and thinking style. She then must demonstrate the validity of the concept to her colleagues and peers; this is the third stage. The impact of a scientifically valid concept, through its application, extension, or possibly dispute, leads to the consideration of new concepts, and the process repeats.

In the western/northern academic tradition an axiomatic demonstration of validity has greater merit than a relational demonstration [2]. Even when the validation is empirical, which is essentially a strong relational argument though an incomplete axiomatic one, often the case in biology or medicine, the validation is communicated in a axiomatic manner [7]. To accept validation in the axiomatic style, the scientist must understand the concept in that style. Roger Penrose says, "We must 'see' the truth of a mathematical argument to be convinced of its validity. This 'seeing' is the very essence of consciousness." [8] Furthermore if the epistemology is axiomatic, it is likely that the discovery was made in a axiomatic style. The process appears to exclude relational thinkers.

However Penrose, whose mathematics ranges far beyond the academic, explicitly acknowledges diversity: "There seem to be many different ways in which different people think - and even in which different mathematicians think about mathematics." Relational thinking has long been associated with creativity [9], and a famous example illustrates creativity in science through relational thinking:

> “The way the two triple sets of axioms are contrasted in (the book) is not at all the way things happened in the process of actual thinking. This was merely a later formulation of the subject matter.” - Albert Einstein, quoted in [10]

As the quote suggests and as Figure 4 illustrates, relational thinkers active in science develop a second epistemology, and cross over to communicate their work in a culturally acceptable manner.

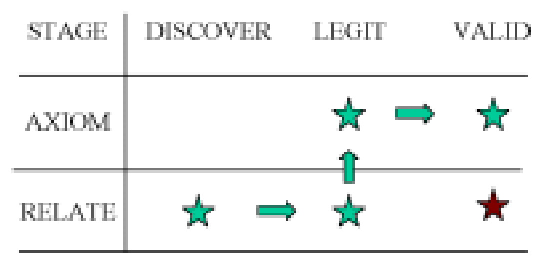

Figure 4: Thinking styles in the scientific process.

In fact a sign of a mature scientist, whatever her natural thinking style, is the ability to think in both styles. Theoretical results must match experimental evidence and some standard of reasonable behaviour for the system, and the converse. Scientists continuously check the results of one process using another process, and an unexplained mismatch in results is considered unsatisfactory. Figure 4 illustrates validity in both styles. Formally, for any scientific result, the following rules apply.

- Axiomatic validity is necessary, but not sufficient; the result must also be consistent with all related observations and results.
- Consistency with all related observations and results is necessary, but not sufficient; an axiomatic argument must lead to an equivalent result.

In other words, once the lens of the academic tradition is removed, axiomatic and relational styles have equal weight.

Some works on women's role in science have focused on the epistemology, e.g. [11, 12] and some of the essays in [13], arguing the relative merits of traditional scientific or feminist epistemologies, as if one would replace the other. Such arguments arise because of a confounding of the legitimacy and validity stages of the scientific process. Whether discussing research or pedagogy, the writers are concerned with how knowing (their word) or legitimacy (this paper) is achieved by the researcher/student. For legitimacy, different thinking styles work for different people; researchers use multiple styles and inclusive pedagogy employs a diversity of approaches. At the third stage, one style of validation cannot replace the other; all styles must reach the same result. Any other condition would limit the generality and transferability of the science. The epistemology arguments cited do little to advance either science or women's participation in it.

INFOGRAPHICS

In this section, we briefly explain a new concept, leaving a more complete explanation to a separate article [14], in order to advance the discussion beyond the point at which it usually stalls: the argument for diversity in science thought and culture.

Infographics: The statistics, patterns, and trends in information; the characteristics of the information landscape.

Consider that 40 years ago, a typical scientific instrument displayed a number or generated a line on a chart recorder. Today, there are multiple instruments in place of the one, each capable of sampling the same parameter at 1000 times the resolution, thousands of times per second. Technology has enabled increasing amounts of information to be collected, processed and stored. Further vast quantities of information are artificially generated through deterministic and statistical modelling and DSP in its many forms. The quantity of information in STEM is increasing rapidly.

Infographics charts these changes in the information landscape. Infographers observe that as quantities increase, patterns emerge, then patterns become more complex, subject areas emerge, become complex, and merge eventually into a new field or new technology. The organizing principle (patterns) tends to be relational rather than axiomatic. Examples of relational technologies are fuzzy logic as used in automation and control, the world wide web, and climate modeling.

Another example is nonlinear dynamics, a rapidly developing field of science better known in some of its popular manifestations: chaos theory, complexity theory, and fractals. Simple patterns repeat at different scales, and simple laws give rise to apparently chaotic systems. Nonlinear dynamics provides tools for organizing and making sense of large quantities of information, and has applications in biology, economics, astronomy, information theory. Some important pieces of the theory are axiomatic in nature, but the overall character of the field is clearly relational.

Infographics show that progress (discovery and legitimacy) in science will depend increasingly on relational thinking styles. As in the past, axiomatic and relational styles have equal weight in establishing validity of scientific results, and as always, a diversity of approaches enriches knowledge.

Activation of relational thinking in science requires participation by people whose natural style is relational, as well as respect and encouragement for relational thinking in pedagogy and in evaluation. In particular, academic science must develop new traditions in which axiomatic and relational styles have equal merit.

SUMMARY

Axiomatic and relational characteristics illustrate diversity in thinking styles. The academic tradition in science favours axiomatic communication and pedagogy, but the relational style is an agent in creativity, and scientific validity is established through a diversity of styles. Infographics indicate that new science and technology will rely increasingly on relational thinking. The conclusion is that encouraging a diversity of thinking styles, particularly in universities, will foster the development of, and broader participation in, science and technology.

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