Toward a General Theory of Scientific Discovery

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In the present paper, we modify and extend an earlier account (Tweney, 1989). Specifically, five levels of a framework for the interpretation of scientific protocols (e.g., laboratory diaries) are redefined to enhance their utility for historical cognitive reconstruction of scientific episodes. Such episodes possess "dynamics" which emerge with varying degrees of clarity depending upon the level of analysis. From the lowest frequency dynamics to the highest, these are as follows:

Level 1: Purposes
Level 2: Heuristics
Level 3: Scripts & Schemata
Level 4: Goals & Subgoals
Level 5: States & Operators

The levels constitute a partially decomposable hierarchy in which purposes are implemented by a selection of problem-solving heuristics, which in turn are implemented using scripts and schemas. Each script or schema is then instantiated via a series of goal-driven activities which can be represented as the transformation of mental states by operators that transform one state into another. Thus, a particular script (for example, "Wind a coil") can be decomposed into specific subgoals ("Obtain wire," "Wind wire on core," etc.), which in turn can be decomposed into specific States and Operators. While our use of terminology in the levels sometimes differs from existing cognitive theory, it can be shown that the analysis is consistent with existing accounts of scientific activity.

The theory accommodates concerns derived from both the humanities (e.g., the history of science, culture studies) and the sciences (e.g., dynamic systems theory): both are necessary to account for the complexity of real-world thinking in a socially- and culturally-conditioned domain. We thus blend interpretive ("humanities-like") and scientific ("explanatory") accounts.

Three examples from our own work illustrate the advantages of the account. Thus, Duncan & Tweney (1997) have shown that Faraday's developing representation of aspects of his field theory can be accounted for by positing a "representational spillover" from one domain to another. Here, Faraday's long-term purposes (Level 1) were instantiated via specific heuristics (Level 2), which interacted in productive fashion with his concept of the field.

Ippolito & Tweney (1995) showed that Faraday's work on acoustics in 1831 (just prior to his August discovery of induction) manifested a progression from perceptual rehearsal through "inceptual rehearsal," in which selective aspects of his perceptual experiences were enhanced and "run" in stand-alone fashion. The resulting inceptions formed the basis for a mental model, which was manifested in physical apparatus. Here, specific heuristics (Level 2) were instantiated via repeated use of scripts (Level 3), which in turn modified the heuristics, and so on; only then was physical instantiation (Levels 4 and 5) possible.

The present account can incorporate explicit representation of cultural and historical dynamics. For example, a recent investigation (Kurz & Tweney, in press) of the representational use of differential equations relied upon the representational multiplicity of the calculus (recoverable from the rich history of the calculus) to uncover the purposes and heuristics (Levels 1 and 2) at play in the real-time attempts of expert physical scientists and mathematicians to solve a physical rate problem.

Here, representational change was capturable by using the rich historical context of the cultural artifact that constitutes modern calculus. Such "archeology" of knowledge proves fully consistent with even the most molecular accounts of problem-solving activities.

References

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