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EXPLORATORY PROBLEM-SOLVING IN SCIENTIFIC REASONING

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Our research focuses on exploratory problem solving through model construction and adaptation as frequently exhibited in scientific discovery. We employ the following methods:

- cognitive-historical analysis of historical cases,
- analyses of problem solving protocols that exhibit similar expert reasoning processes, and
- computational modeling of these protocols and case studies.

On our interpretation, exploration through constructing imaginary models of field processes figured centrally in J. C. Maxwell's reasoning in creating the field equations for electromagnetism (see Nersessian 1992,1995; Nersessian & Greeno 1989). This construction involved abstracting and applying generic models (see also Griffith, Nersessian & Goel 1996). The historical records, however, fail to provide adequate constraints. To further examine our hypotheses about Maxwell's reasoning we have focused on similar reasoning found in a verbal problem solving protocol about springs (Clement 1989). Here we focus on one aspect we posit is common to both cases: constructing imaginary models through "function-follows-form" transformations.

Major requirements for constructing computational models of both cases are the ability to account for: 1. the representation, organization, and indexing of models, 2. multi-strategy reasoning, 3. flexible and dynamic control of problem solving, and 4. abstraction and application of generic models. Computational theories of evolutionary design ("adaptive modeling") (Goel 1991) and creative design ("model-based analogy") (Bhatta & Goel 1993) instantiated in the KRITIK and IDEAL systems respectively satisfy these requirements. Adaptive modeling provides a Structure-Behavior-Function (SBF) language for addressing requirement 1, and a Task-Method-Knowledge (TMK) language (Goel *et. al.* 1993) which satisfies requirements 2 and 3. Finally, Model-Based Analogy (MBA) provides a method for knowledge transfer which uses generic models satisfying 4.

One important issue in both of our case studies is to find the behavior of a particular physical system given its form. This is the task in the S2 case, e.g., find the amount the spring will stretch given the diameter. Thus far we have developed a computational system, TORQUE, that models S2's discovery of torque in springs. A key computational characteristic of TORQUE is its application of structural transformations to the structural and topological elements of SBF models of a known system to generate new models of real and imaginary systems. TORQUE performs a type of transformation which we call "function-follows-form" in which the construction of new models is based upon transformations to their form, but evaluation of these models requires the derivation of their behaviors. To achieve "function-follows-form" transformations TORQUE uses knowledge structures which we call Generic Structural Transformations (GSTs). After retrieving an initial source analog via MBA, TORQUE evaluates the model by attempting to reduce the differences between the target and the analog model. This evaluation process involves either retrieving generic models of physical principles (GPPs) which can explain away the differences, or applying GSTs to transform the target or source models. These transformations bring new knowledge to the task which may lead TORQUE towards or away from the initial goal. TORQUE discovers the GPP of torque while attempting to reduce the differences between a circular and an imaginary square coil. Through TORQUE we have established that in the S2 case "function-follows-form" transformations play a significant role in the exploratory process. We hypothesize that "function-follows-form" transformations also play a significant role in Maxwell's exploration of electromagnetism.

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