Title
Imagistic Simulation in Scientific Model Construction

Journal
Proceedings of the Annual Meeting of the Cognitive Science Society, 25(25)

ISSN
1069-7977

Author
Clement, John J.

Publication Date
2003

Peer reviewed

Imagistic Simulation in Scientific Model Construction

John J. Clement (clement@srri.umass.edu)
Scientific Reasoning Research Institute
College of Natural Sciences and Mathematics
and School of Education
Lederle GRT 434
University of Massachusetts
Amherst, MA 01003 USA

Abstract

The role of mental simulation in scientific learning processes is poorly understood. This paper examines video taped model construction protocols from an expert and a student to generate initial hypotheses concerning: the relationship between "runnable" schemas and imagery during mental simulation; and how assembling a scientific model from simpler runnable schemas can "transfer runnability" to the model. By the end of their learning episodes both the expert and the student appear to have acquired something more than a new symbolic relationship. They appear to have an imageable, runnable model where the imagability and runnability have been transferred or "inherited" from a source analogue. One source of support for this finding comes from observing similar depictive hand motions as subjects thought about the analogue case and later about the developing target model. Understanding schema driven imagistic simulations may eventually help us resolve the apparent paradox involved in learning from "running a new thought experiment in one's head."

Imagistic Simulation in Scientific Discovery

Studies that examine the link between schematic knowledge, complex learning and imagistic reasoning have been largely unexplored. One of the basic needs is to characterize various types of imagistic reasoning as well as observational correlates for them. The purpose of this study is to generate hypotheses that have initial grounding in multiple observations from transcripts in two case studies where subjects appears to mentally simulate the behavior of a system via imagery. One type of motivation for the study comes from other studies indicating the important role of thought experiments in scientific discovery (Nersessian, 2001). Another comes from the need to understand how students can best develop runnable mental models of scientific phenomena. The data base for the first case study comes from ten professors and advanced graduate students in scientific fields who were recorded while thinking aloud about the following problem, illustrated in Figure 1:

Spring Problem: A weight is hung on a spring. The original spring is replaced with a spring made of the same kind of wire, with the same number of coils, but with coils that are twice as wide in diameter. Will the spring stretch from its natural length more, less, or the same amount under the same weight? (Assume the mass of the spring is negligible.) Why do you think so?

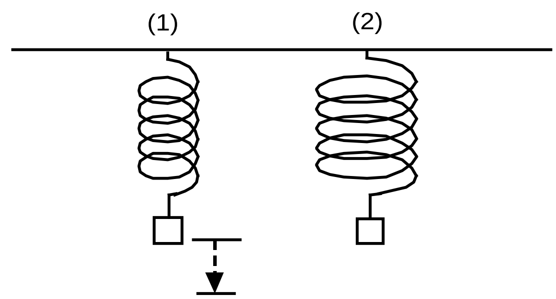

Figure 1

This data base has yielded previous findings on analogies and creative model construction cycles (Clement, 1988, 1989, 1998; Griffith, Nersessian, and Goel, 2000). For example, the 1988 paper coded frequencies for different types of analogies across all subjects in the data base, and the 1998 paper extended this analysis to other tasks. But the present work on imagery is at an earlier stage, because we do not yet have a stable set of observation concepts and theoretical concepts relevant to the use of imagery and simulation that have any grounding in clinical studies. For these purposes the present study develops exploratory case studies for two protocols from an expert and a student.

Given the previous work of others I will assume the existence of analog imagistic representations that have explanatory power for cognitive theory at a certain level of processing and assume that these subjects are capable of generating imagery. But this still leaves other important questions. Can it be used in higher level cognition? Can we develop observation concepts allowing us to tell where in a protocol a subject is using imagery? Can it be kinesthetic? Can subjects interrogate a newly formed image of a novel situation to learn from it? What is its relation to schemas and mental simulation?

I will first consider a case study of expert subject S2; video tapes for S2 have recently been reanalyzed to identify depictive hand motions and other observations that are potentially relevant to imagery and simulation use. S2 is not an engineer or physicist and is therefore working at the frontier of his own personal knowledge on an unfamiliar problem here. For the spring problem subject S2 first generated an analogy in which he predicted that a long horizontal rod fixed at one end would bend more than a short one (with the same weight attached to the other end of each rod), inferring that segments of the wider spring would bend more and therefore stretch more (a correct conclusion.) However, he was concerned about the appropriateness of this model at a deeper level because of the apparent lack of a match between bending producing an increasing slope in the rod and a lack of increasing slope in the wire in a stretched spring. One can visualize this discrepancy here by thinking of the increasing slope a bug would experience walking down a bending rod and the constant slope the bug would experience walking down the helix of a stretched spring. (This is my own descriptive analogy for purposes of clarity- not the subject's.) This discrepancy led him to question whether the bending rod was an adequate model for the spring.

Protocol Section 1

> "But then it occurs to me that there's something clearly wrong with that [bending rod] metaphor, because ..it would (raises hands together in front of face) droop (moves r. hand to the right in a downward curve) like that, its slope (retraces curved path in air with l. hand) would steadily increase, whereas in a spring, the slope of the spiral is constant… "

This anomaly or mismatch appears to bother him considerably and drives further work on the problem. In the case of the rods though, he says:

> "I have a strong intuition--a physical imagistic intuition--that this [longer rod] will bend a lot more than that [shorter rod] will."

I will use underscored type to identify observations that have potential as evidence for imagery (both kinesthetic and visual) and simulation use, such as the depictive hand motions and the spontaneous imagery report above.

Polygonal Springs After spending nearly 30 minutes considering this and other analogies, he generates the polygonal coil models in Figures 2 & 3. While analyzing the hexagon in terms of bending effects below, it occurs to him in an Aha episode that there will also be *twisting* effects in the segments.

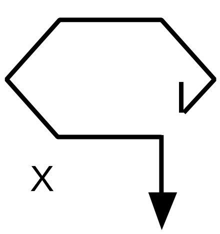

Figure 2

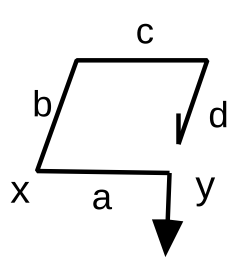

Figure 3

Protocol Section 2

> "Just looking at this it occurs to me that when force is applied here (at arrow in Figure 2), you not only get a bend on this segment, but because there's a pivot here (point x), you get a torsion [movement and strain produced by twisting of the wire] effect. Aha!! Maybe the behavior of the spring has something to do with twist (makes twisting motion with right hand) forces as well as bend forces. That's a real interesting idea."

Twisting of the wire and the resulting torsion is in fact a key element in the analysis of spring behavior as understood by engineers. Its discovery here represents a major insight in finding a new causal mechanism. The torsion discovery and Aha! phenomenon above is an interesting process in itself and is discussed in Clement (1988,1989). However in this paper I want to focus on examining the possibility that imagistic simulation plays a role in evaluating and making inferences from these new models. The subject continues:

> "Let me accentuate the torsion force by making a square where there's a right angle. I like that, a right angle. That unmixes the bend from the torsion. Now I have two forces introducing a stretch. I have the force that bends this segment a (Figure 3) and in addition I have a torsion (makes twisting motion with right hand) force which twists (rod b) at vertex, um, x" (as if side a were a wrench acting to twist side b.)
>
> "Now let's assume that torsion and bend (makes bending motion with hands together) don't interact…does this (points to square) gain in slope--toward the bottom? Indeed, we have a structure here which does not have this increasing slope as you get to the bottom. It's only if one looks at the fine structure; the rod between the Y and the X, that one sees the flop (moves left hand horizontally in a downward curve) effect."
>
> "Now I feel I have a good model of sp- of a spring."

Because bending and twisting still allow the slope to "start over from zero" at each corner, the square coil is a new model in which the accumulating slope difficulty does not occur, suggesting a way to resolve his previous anomaly. He goes on to ask about the effect of coil width for the square coil model.

> "Now making the sides longer certainly would make the [square] spring stretch more… The longer the segment, (holds hands up in front as if holding something between them) the more (makes bending motion with right hand) the bendability. "

Protocol Section 3

> "Now the same thing would happen to the torsion I think, because "If I have a longer rod (moves hands apart), and I put a twist on it (moves hands as if twisting a rod), it seems to me--again, physical intuition--that it will twist more. " I'm (raises hands in same position as before and holds them there continuously until the next motion below)… imagining holding something that has a certain twistyness to it, a-and twisting it…Again, now I'm confirming (moves right hand slowly toward left hand) that by using this method of limits. As (moves right hand slowly toward left hand until they almost touch at the

> word "closer") I bring my hand up closer and closer to the original place where I hold it, I realize very clearly that it will get harder and harder to twist. So that confirms my intuition so I'm quite confident of that…."

(The reader may wish to try this thought experiment with images of coat hanger wire, bent to have "handles" at each end of the wire.) Later the subject distinguishes between confidence in the answer to the spring problem and confidence in his understanding of it, and indicates that the torsion analysis has increased his subjective feeling of understanding:

> "Before this torsion insight, my confidence in the answer [for the spring problem] was 95% but my confidence in my understanding of the situation was way way down, I felt that I did not really understand what was happening. Now my confidence in the answer is near 100% and my confidence in my understanding is like 80%."

At this point S2 appears to have a mental model of the spring as working like a square coil that contains elements that both bend and twist. Both of these factors predict correctly that the wider spring will stretch more. The model also suggests that the slope of the stretched spring will be constant throughout (also correct), resolving S2's previous anomaly about increasing slope.

Use of Imagistic Simulation Underscored type above in Section 3 identifies examples of several imagery-related observation categories, in the following order: **personal action projections** (spontaneously redescribing a system action in terms of a human action, consistent with the use of kinesthetic imagery), **depictive hand motions**, and **imagery reports**. The latter occurs when a subject spontaneously uses terms like "imagining," "picturing," a situation, or "feeling what it's like to manipulate" a situation. In this case it is a **dynamic imagery report** (involving movement or forces). These observations appear alongside new predictions at many points in the protocol, including predictions for novel situations like the square coil.

None of these observations are infallible indicators on their own, but I take them as evidence for imagery, especially when more than one appear together. (There is not space for a review here, but an increasing variety of studies of depictive gestures suggest that they are expressions of core meanings or reasoning strategies and not simply translations of speech. Others indicate that the same brain areas are active during real actions and corresponding imagined actions.) Taken together with the subject's new predictions, the observations above can be explained via what I have called *imagistic simulations* wherein: (1) the subject: has activated a somewhat general and permanent perceptual motor schema that can control the action of twisting real objects; (2) the schema assimilates an image of two rods of different lengths that is more specific and temporary; (3) the action schema "runs through its program" vicariously without touching real objects, generating a simulation of twisting the two rods, and the subject compares the effort required for each. Such a simulation may draw out implicit knowledge in the schema that the subject has not attended to before--e.g. in this case the simulation may draw out knowledge embedded in analog tuning parameters of a motor schema. In other words, a hypothesis can be made, with initial grounding in data such as that in protocol section 3, that the subject is going through a process in these episodes wherein a general action schema assimilates the image of a particular object and produces expectations about its behavior in a subsequent dynamic image, or simulation.

A perceptual motor action schema is hypothesized to contain three major subprocesses: a subprocess for assimilating (instantiating) objects in the environment based on preconditions for application; a subprocess for implementing and tuning or adjusting the action so that it is appropriate for this particular object; and a third subprocess for generating expectations about the results of the action - in this case, an image of how far the rod will turn. The idea that a schema can have generality through a pattern of actions and expectations over time with parameters adjusted to a particular situation in a process of tuning has early precedents such as Schmidt (1982). The important cognitive role played by actions involved in scientific experimental practice has been documented by Tweney (1986) and Gooding (1992). Perceptual motor schemas may not be the only kind of schemas capable of generating imagistic simulations, but in the examples discussed here they appear to serve as an important type that is amenable to initial analysis.

Hegarty (2002) points out that visualizations can exist both externally, as in a drawing, or internally, and that various relations are possible between these. Other images in this protocol (e.g. the square coil in section 2) are supported by external drawings. But the images are not fully comprised by the external drawings, since the drawings do not capture his conceptions of movement and deformation that is such a prominent feature of these protocols. "Projections" of imagery onto drawings has also been studied by Trickett and Trafton (2002). And although the hand motions themselves could also be considered to be an external representation, there are also a number of similar instances of reasoning about twists and bends in the complete protocol where one of the other imagery indicators in bold type above may appear without a hand motion. Therefore I have hypothesized the use of internal dynamic imagery that is sometimes expressed via depictive hand motions. In this study I am primarily interested in depictive hand motions as providers of evidence for internal imagery when they do appear.

Imagery Enhancement The extreme case episode in Section 3 above poses an interesting challenge for theory because it simply seems to repeat the same reasoning as the previous twisting episode, but yields a much higher level of confidence. Weld (1990) has proposed that one mechanism for the effectiveness of an extreme case is to allow access to the second of two data points (pairs) for the values of two related variables. If one assumes a monotonic relationship one can predict an increasing or decreasing function from knowing two data points. But how can considering the extra extreme case above add so much confidence since S2 has already just consulted his knowledge on this issue and already has the equivalent of at least two "data points"? It is difficult to see how this small change in the value of one variable could generate a new deduction about the variables to produce considerably greater conviction. And his saying " I realize very clearly that it will get harder" indicates there is something special about the extreme case that makes it count more than simply adding a third data point from which to induce a pattern. A hypothesis that explains this is the following. Given the above observations it is more plausible to interpret this process as "imagery enhancement" (or "simulation enhancement")— that the role of this extreme case is to enhance the subject's ability to run or compare imagistic simulations with high confidence, and that this comes from increasing the difference between the two images being compared and making that difference more detectable under inspection of the images. In this case the main source of conviction in the simulations appears to be the tapping of implicit knowledge embedded in a motor schema and its conversion into explicit knowledge. The extreme case makes differences in implicit expectations more "perceivable" in this case. A second problem that questions the adequacy of describing this as "accessing a stored data point" is its difficulty in explaining the hand motions and imagery reports. Why did the subject bother to run through an extra (extreme case) simulation? The fact that he did so suggests the view that he was applying knowledge that was not stored as a linguistic description. For if it were already explicitly described, then why form an image of the situation and make the effort to run through a simulation of it? Why not just report it? Thus the imagistic simulation concepts developed so far can explain the effectiveness of the extreme case at the end of the transcript above as an example of "imagery enhancement," a phenomenon difficult to explain in other ways.

Can the phenomena above be explained by imagery alone without positing a role for schemas? There is evidence for a negative answer here in favor of the theory of having schemas be separate entities from the more specific images they assimilate and operate on. The same twisting schema appears to be able to run on different images here (long, short, and very short rods, as well as the square and hexagonal coils). And conversely, one can find evidence in other cases of a single image being assimilated by different schemas, as in the case of both the bending and twisting schemas applied to the single image of the square coil; or applied to the single image of a straight rod. These considerations motivate the idea of having a two element theory for an imagistic simulation with one or more schemas operating on a specific image. In an exploratory clinical study, even within the protocol of one subject, accounting for multiple instances like these helps constrain the theory by the need for it to explain different episodes. This theory of imagistic simulation is developed more fully for data from more expert subjects in Clement (1994).

Thought Experiments The twisting rod episode above is also an example of an **untested thought experiment** in the broad sense, a term I have used to refer to the act of predicting the behavior of an untested, concrete, but absent system (the "experiment") (Clement, 2002). Aspects of the experiment must be new and untested in the sense that the subject is not informed about their behavior from direct observation or from an authority. How can S2 learn anything by focussing on the particular example of the rod and running through the experience of twisting it? How can it give the sensation of "doing an empirical experiment in one's head" (Nersessian, 1991)? This raises what I term the **fundamental paradox of thought experiments**, expressed as: How can findings that carry conviction result from a new experiment conducted entirely within the head?

One can use the imagistic simulation concepts developed so far to conjecture several possible sources of new information and conviction in thought experiments including: perceptual motor schemas that are general enough to generate and run imagistic simulations with conviction in a variety of situations within their domain of application; the flexible extended application of such a schema to a case outside of its normal domain of application; or the tapping of implicit knowledge in the schema. More general spatial reasoning processes may also be involved, such as the constraint that solid objects may not occupy the same space. One can point to such sources as potential origins of new information and conviction in thought experiments, to help us begin to explain the fundamental paradox. Under the above definition, running a newly constructed model like the square coil is also an untested thought experiment--analyzed here as a compound simulation involving two runnable schemas working together on a common image. The ability to run compound simulations is another important possible source of new information in thought experiments. These ideas suggest directions for further study.

Transfer of Imagery and Runnability To Models One can also pose the hypothesis that a model constructed using runnable schemas can inherit the simulation-generating capability (runnability) of those schemas. I refer to this as a "transfer of runnability" from a runnable schema (source analogue) to a more complex model. For example, the square coil model constructed by S2 appears to tap runnable schemas for bending and twisting as sources. Evidence for transfer of runnability is provided by the twisting rod episode, since he gives evidence from similar hand motions for imagining twisting in the rod and twisting in the square coil, and for making predictions from each of these. The similar hand motions suggest that the form of the imagery is similar in both cases. Because the torsion idea plays the role of an axiom or grounding primitive in this solution, this also illustrates the idea that such an axiom can have content that is expressed imagistically, and that in some cases can be embodied in the perceptual-motor system. That is, this expert's explanation is grounded in concrete intuitions from perceptual motor schemas that play a role somewhat like axioms as the foundation for his other arguments, but which also appear to play a role as primitive sources of sensemaking that make his model a satisfying locus of understanding.

Compound Simulations These observations suggest that he is generating new information by running the twisting and bending schemas repeatedly for different sides within the square coil model and within its spatial and geometric constraints as a new compound simulation, rather than making a set of formal deductions from previous facts. (Transferring runnability from a source analogue schema in this way does not guarantee a correct model or even the ability to run the entire model if the schema provides only a piece of the model, but it does provide an important part of what is needed to run the model.) I hypothesize that the runnability of these elements in a compound simulation in the square spring model, along with the imagistic "summing" or canceling of the effects of these applications via spatial reasoning, is what allowed him to "interrogate" the model to generate the emergent property of no cumulative bending in the coil, as well as the prediction that a wider coil will stretch more. This suggests that compound simulations of novel systems can support physical/spatial inferences about trajectories and additive or non additive effects. Transfer of runnability from the twisting schema to the square coil model appears to enable the generation of new emergent properties from that model. Because these resolve an earlier anomaly, this lends credence to his model.

Imagistic Simulations and Transfer of Runnability in Instruction

It is possible that the runnability of a scientific model can support desirable properties such as flexible interrogatability for other implicit properties, and flexibility of application of the model to other cases or transfer problems. Clement and Steinberg (2002) analyzed video tapes of a high school student being tutored in an electricity curriculum which used analogies to attempt to construct models of electric potential (voltage) and charge flow (current) that were anchored in the student's intuitions about (perceptual motor schemas for) pressure and air flow. The student was given eight hours of interactive tutoring over five days. Care was taken over several instructional sessions to develop an imagable model by starting from concrete analogue examples of pressure (e.g. a leak in a tire) and using student generated drawings with a color coding scheme for different levels of "electric pressure". This subject was able to map and apply an air pressure and flow analogy to electric potential and current as her tutor helped her build a model for electric circuits. This led the authors to hypothesize a transfer of runnability from the analogue air pressure conceptions to the electric potential model. and continued to exhibit traces of it in a posttest interview on a relatively far transfer problem after instruction. The hypothesis is supported here by evidence from the subject's spontaneous use of similar depictive hand motions over drawings during the original air analogy, and during the instructional circuit examples, indicating that she was using a similar type of imagery in both cases.

Table 1: Similar Depictive Hand Motions as Evidence for Transfer of Runnability

Stage	**Context**	**Gesture**	**Quotation**
Tire Analogy	Leak in Tire	Moves fingers over path of escaping air in drawing	"You're going to allow an escape for the air."
		(Puts hands together as if surrounding a 5" diameter object)	You have a high concentration of air in the tire, which is really under a lot of pressure
Applying Pressure Ideas to Circuit	Capacitor discharging to light a bulb for 2 sec.	(Puts hands together as if surrounding a 5" diameter object, then pulls them apart)	Once it's [the charge built up in capacitor] got that room to move -- that place to expand "...
		Moves fingers over path in circuit drawing	The pressure is gonna take that path
Application of Model in Post Test Transfer Problem	Complex circuit with 4 bulbs, switch and battery	(Color codes drawing for pressure levels) Moves finger down over bulb at lower left Repeats motion	It will start out as yellow..." Greater movement, greater flow across -- through this bulb
		Moves finger from right to left over wire in drawing	So there will be a charge moving through that wire coming from this area of higher pressure to an area of lower pressure."

Table 1 shows examples of some of these parallel gestures. Although there is not space in this paper to describe each problem in detail, they are discussed in Clement and Steinberg (2002). Gestures for both pressure and flow appear in the tire analogy and then during instructional problems on circuits. This is similar to the same "transfer of runnability" process noted for the earlier expert protocol, pointing to a possible new type of expert-novice similarity. Such expert-novice similarities have provided important insights for curriculum development in science (Clement, 1998.) The possibility of transfer of runnability may expand our notion of the role of analogy in theories of scientific discovery and of science instruction.

Furthermore, after more instruction, she continued to exhibit some of these hand motions in a correct posttest solution for a relatively far transfer problem. By the post test, her expressions of her representation for pressure have changed to color coding strategies developed in the instruction, but hand motions for current flow still remain. Her conceptual terms are not perfect, but quotations such as those at the bottom of Table 1 provide evidence that the instruction fostered development of a dynamic mental model of fluid-like flows of current caused by differences in "electric pressure", that could generate new imagistic simulations for understanding a relatively difficult transfer problem. This example also suggests a generalization from the concept of perceptual motor action schema developed in the first half of this article. It is not clear that the concepts of pressure and flow used here are simple actions like bending and twisting. If they are represented internally by "actions" it would appear to be in a more metaphorical way. Yet they seem capable of driving imagistic simulations.

This case study suggests that the transfer of runnability achieved by grounding a new model in a runnable prior knowledge schema as a source analogue may foster a type of model flexibility that aids the use of the model in transfer problems. Model flexibility would seem to be a very important feature of scientific knowledge for both experts and students.

Further studies that can evaluate and extend our knowledge of the nature of imagistic simulation and model construction in experts and students are very much needed.

Acknowledgements

This material is based upon work supported by the National Science Foundation under Grants RED-9453084 and REC-0231808. Any opinions, findings, and conclusions or recommendations expressed in this paper are those of the author and do not necessarily reflect the views of the National Science Foundation.

References

Clement, J. (1988). Observed methods for generating analogies in scientific problem solving. *Cognitive Science, 12*: 563-586.

Clement, J. (1989). Learning via model construction and criticism: Protocol evidence on sources of creativity in science. Glover, J., Ronning, R., and Reynolds, C. (Eds.), *Handbook of creativity: Assessment, theory and research*. NY: Plenum, 341-381.

Clement, J. (1994). Use of physical intuition and imagistic simulation in expert problem solving. In Tirosh, D. (Eds.), *Implicit and explicit knowledge.* Norwood, NJ: Ablex Publishing Corp.

Clement, J. (1998). Expert novice similarities and instruction using analogies. *International Journal of Science Education*, *20*(10), 1271-1286.

Clement, J. (2000) Analysis of clinical interviews: Foundations and model viability. In Lesh, R. and Kelly, A., *Handbook of research methodologies for science and mathematics education* (pp. 341-385). Hillsdale, NJ: Lawrence Erlbaum.

Clement, J. (2002). Protocol evidence on thought experiments used by experts. In Wayne Gray and Christian Schunn, Eds., *Proceedings of the Twenty-Fourth Annual Conference of the Cognitive Science Society 22,* 32. Mahwah, NJ: Erlbaum.

Clement, J. and Steinberg, M. (2002). Step-wise evolution of models of electric circuits: A "learning-aloud" case study. *Journal of the Learning Scien*ces, *11*, 389-452.

Gooding, D. (1992). The procedural turn: or, Why do thought experiments work? In Giere, R. (Ed.) *Cognitive models of science.* Minneapolis: U. of Minnesota Press.

Griffith, T. W., N. J. Nersessian, and A. Goel (2000). Function-follows-form transformations in scientific problem solving. In *Proceedings of the Cognitive Science Society 22,* 196-201. Mahwah, N.J.: Lawrence Erlbaum

Hegarty, M. (2002). Mental visualizations and external visualizations. In Wayne Gray and Christian Schunn, Eds., *Proceedings of the Twenty-Fourth Annual Conference of the Cognitive Science Society* 22, 40. Mahwah, NJ: Erlbaum.

Nersessian, N.J. (1991). Why do thought experiments work? In *Thirteenth Annual Proceedings of the Cognitive Science Society* . Mahwah, NJ: Lawrence Erlbaum Inc.

Nersessian, N. J. (2001). Maxwell and the method of physical analogy: Model-based reasoning, generic abstraction, and conceptual change. In *Reading Natural Philosophy: Essays in History and Philosophy of Science and Mathematics in Honor of Howard Stein on his 70th Birthday* edited by D. Malamet. LaSalle, IL: Open Court.

Schmidt, R. A. (1982). *Motor control and learning*. Champaign, IL: Human Kinetics Publishers.

Trickett, S. and Trafton, J. G. (2002) The instantiation and use of conceptual simulations in evaluating hypotheses: Movies-in-the-mind in scientific reasoning. In Wayne Gray and Christian Schunn, Eds., *Proceedings of the Twenty-Fourth Annual Conference of the Cognitive Science Society* 22, 878-883. Mahwah, NJ: Erlbaum.

Tweney, Ryan D. (1986). Procedural representation in Michael Faraday's scientific thought. PSA 1986, 2.

Weld, D. (1990) Exaggeration. *Artificial Intelligence*, 43(3):311-368.