Rethinking Technology & Creativity in the 21st Century

Modeling as a trans-disciplinary formative skill and practice

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> *"Today's scientists have substituted mathematics for experiments, and they wander off through equation after equation, and eventually build a structure which has no relation to reality."*
>
> –Nikola Tesla, 1934

> *"No, wait guys. Listen. You guys are so talented and imaginative... but you can't work as a team. I'm just a construction worker, but when I have a plan and we were working together, we could build a skyscraper. Now you guys are Master Builders. Just imagine what you could do if you did that! ...You could save the universe!"*
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> –Emmet, The Lego Movie

We have argued previously for seven "tools for thinking" that underlie trans-disciplinary thinking and creativity (Mishra, Koehler, & Henriksen, 2011). Inspired in part by the Root-Bernstein's (1999) work in this area, we argue that these skills encapsulate the ways in which creative people think. These seven skills are: Perceiving, Patterning, Abstracting, Embodied Thinking, Modeling, Play, and Synthesizing. Our last article (Henriksen, Good, & Mishra, in press) was on the skill of Embodied Thinking, while this article focuses on Modeling.

Introduction

Late in the summer of 2013, Elon Musk set the Internet ablaze with a "napkin sketch" of the Hyperloop Alpha, his futuristic vision for mass transit (Christensen, 2013). Musk backed his rudimentary doodle with a 57-page memo where he aimed to keep "numbers to a minimum and avoid formulas and jargon" and apologized, "in advance for [his] loose use of the language and imperfect analogies" (Musk, 2013). The memo is a thorough, visually stunning and inspiring proposal for a high-speed mass transit line between Los Angeles and San Francisco wherein passengers travel at speeds up to eight-hundred miles per hour above already existing highways. As The New Yorker magazine noted, "Musk has put forth a plausible idea that doesn't require yet-to-be-developed technologies" (Friend, 2013). The memo and it's 25+ visual sketches, drawings, and figures is, however, the blueprint for something much more impressive than a regional transit line. Instead, the memo presents a promising, innovative, and potentially transformative model that may completely redefine mass transit in the 21st century.

Unsurprisingly, Hyperloop Alpha was developed by one of the most prolific and ambitious innovators in modern time (Fallows, 2013). Elon Musk, who is best known for his leadership roles with PayPal, SpaceX, Tesla Motors, and SolarCity, follows a great lineage of innovators, scientists, engineers, and thinkers who routinely sketch and model. Other famous thinkers such as Jobs, Turing, Wells, Fleming, Pasteur, and Leonardo da Vinci routinely sketched and modeled their ideas, designs, and observations (Hodges, 2012; Isaacson, 2014; Isaacson, 2013; Root-Bernstein, 1999). From Atanasoff's "full-scale model" of an early computer in 1942 (Isaacson, 2014, p. 60) to Watson and Crick's early, often failed attempts to model the double helix of a DNA strand (Watson, 1968), the origins of today's commonplace technologies can be traced to elementary, often imperfect models.

The act of modeling requires us to create a representation (whether scaled down, or scaled up) of some sort of artifact, phenomena, idea or process, in order to make it more conceptually manageable. Taking something that is complex or difficult to experience and creating a representation is essential to making it understandable; or, building a model as a plan for something in order to represent and understand the idea in tactile or real world terms, before it becomes an actuality.

Because of a model's ability to "make accessible something that is difficult to experience easily" (Root-Bernstein, 1999, p. 229) and the fact that modeling is how we represent

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new ideas, build theories, and test their veracity, we argue that modeling is a fundamental cognitive tool that underlies trans-disciplinary thinking and creativity. Scientists use models to understand complex phenomena that they cannot always see or touch (from the incredibly large, such as galaxies, to the incredibly tiny, such as the structure of DNA or the interactions between subatomic particles). Artists use models too, as they sketch out their work before making it a reality. And, in a blend of mathematics and art, architects and engineers use modeling to create sketches or blueprints of buildings and structures before any foundation work is done. Given the foundational nature of modeling as a thought process for many types of work and thinking, we suggest, that it ought to be an essential component of education and teaching. In this article we explain our conceptualization of what we mean by modeling, outline modeling as being of value both as a process and a competency, across disciplines and professions. We expand on its role in teaching and learning and conclude with examples of pedagogy that fosters creativity through this cognitive tool.

Models & Modeling

The ability to model and the process of modeling is one of the skills discussed in Robert and Michele Root-Bernsteins' Sparks of Genius. The authors argue that a model is "designed to depict an actual or hypothetical real-life situation" (p. 229). Building on the Bernstein's work, Mishra, Koehler & Henriksen (2011) also lay out modeling as one of their seven trans-disciplinary skills, which is essential for effective, creative thinking. Creative people use this skill when they alter the scale of things (e.g. when engineers use two-dimensional blueprints to build objects in three dimensions, or vice versa). However, this dimensional thinking is not the only aspect of modeling – in reality it is often paired with abstractions and analogies to help create representations of things or processes that explain the real world (Mishra, Koehler & Henriksen, 2011).

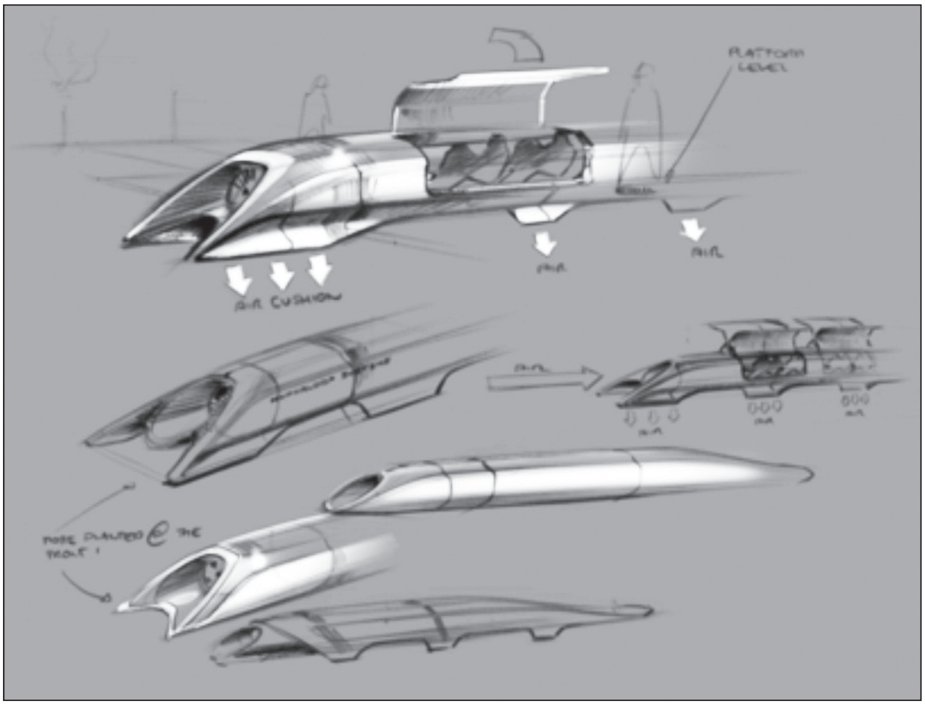

Figure 1. Hyperloop Alpha passenger pods; Elon Musk; August, 2013

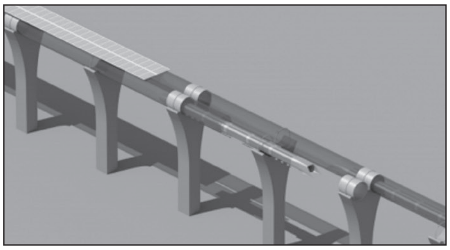

Figure 2. Hyperloop Alpha track; Elon Musk; August, 2013.

In this way models are methods of characterizing and embodying the aspects of something that are critical to how it functions and/or to its structure. As we have noted, models are not just common, but are actually essential, in many fields. As engineers, artists, and scientists can attest, a sketched model can help to identify problems before committing countless hours; and in the areas of art or design work, preliminary sketches are essential, and; sketching a model or design can allow individuals to consider scale, form, and function.

Models can be *representational* (or *physical*), such Elon Musk's model of the Tesla sedan, or *functional, theoretical,* or *imaginary.* A business model is an example of a *theoretical* model as it embodies the basic ideas that show how a process works, and an *imaginary* model aims to provide a visual or tactile representation of the things that cannot be seen (Root-Bernstein, 1999). Sophisticated models may combine

Figure 3. Elon Musk with clay model of Tesla Model S; The New Yorker; August, 2009

two, three, or all four types. With these various model types, modeling calls on the imagination, the observation, the understanding, and the engagement of the modeler. Accordingly, Root-Bernstein (1999) suggest that one of the central things that modeling can do is to provide us with a significant degree of control over a condition, object or a concept. Or vice-versa, it can show the modeler just where there are gaps in the understanding or controls over the process or idea. Models allow us access to information and the ability to manipulate it (within the modeled situation). They show us what we know and what we don't know. Models can only be developed after a real system has been carefully observed, had the important features abstracted from it, been rescaled so that it can be manipulated, and then embodied physically or expressed communicated in some other form (Root-Bernstein, 1999). It is clear with all of this that modeling goes deeper than the actual model, itself. Instead, modeling is a process, such as the process of observing or the process of abstracting, and also a competency, such as the ability to create, sketch, program or form.

The process of modeling requires that the modeler identify, consider, and evaluate the elements of a given system. More, the process of modeling is an organic, iterative process that spans beyond the structured model – it lets us develop new ideas and test them for understanding and veracity. Modeling is a process of which only one is related to the pragmatic development of an actual model. The overall process of modeling, however, is a heuristic process with design, application, evaluation, and redesign. This heuristic process is what leads to multiple iterations of the same model.

The modeling process presents equal chance of success and failure. In addition the modeling process uniquely illuminates faults and errors in a system or design; and from this, the modeler(s) can learn from the mistakes. One of the more key examples of discovery in science came in Watson and Crick's discovery of the DNA double helix. Though their initial models actually failed, it was the learning through failed models and mistakes, which ultimately lead to Watson and Crick's now recognized standard model of the DNA double helix (Watson, 1968). Through the modeling process, modelers are often able to discover unusual and unexpected properties. These unexpected properties may be failures in design or unforeseen successes.

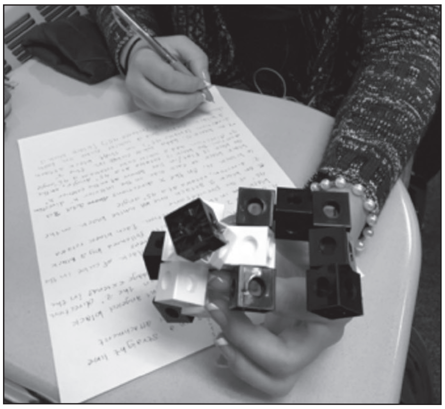

Figure 4. Student practices modeling at Colorado School of Mines (November, 2014)

Modeling is also a competency. Spatial rotation, visualization, mapping, scaling, and analogizing are all skills that support the modeling process as they enable the modeler to build, construct, and conceptualize applicable, useful models. These skills are shared tenets with dimensional thinking, such as three-dimensional models, and visual thinking, such as sketched abstractions.

Mishra, Koehler & Henriksen note that, "modeling requires that we employ abstractions or analogies, and more importantly that we use the facility of dimensional thinking, that is our thinking with respect to space and time" (2011, p. 26). Many have argued that these skills can be fostered, strengthened, and refined through practice and habit. This may involve formal classes or informal experiences of building. Through the opportunity to develop, practice and flex mental modeling skills, the capacity for dimensional thinking and the abstractions/analogies that go into model building are strengthened.

As interconnected and mutually buttressing skills, visual thinking and modeling strengthen one another. Subsequently, it is not surprising that the need to visually think and model is present in different professional disciplines – and therefore becomes important to the field of education overall, particularly in technology-rich contexts.

Modeling as a Learned Competency

Visual and spatial ability, as defineZience (Mohler, 2010). This definition is similar to Root-Bernstein's detailing of dimensional thinking which "involves moving from a 2-D to a 3-D or vice versa; mapping, scaling, or altering the proportions of an object or process within one set of dimensions; and conceptualizing dimensions beyond space and time as

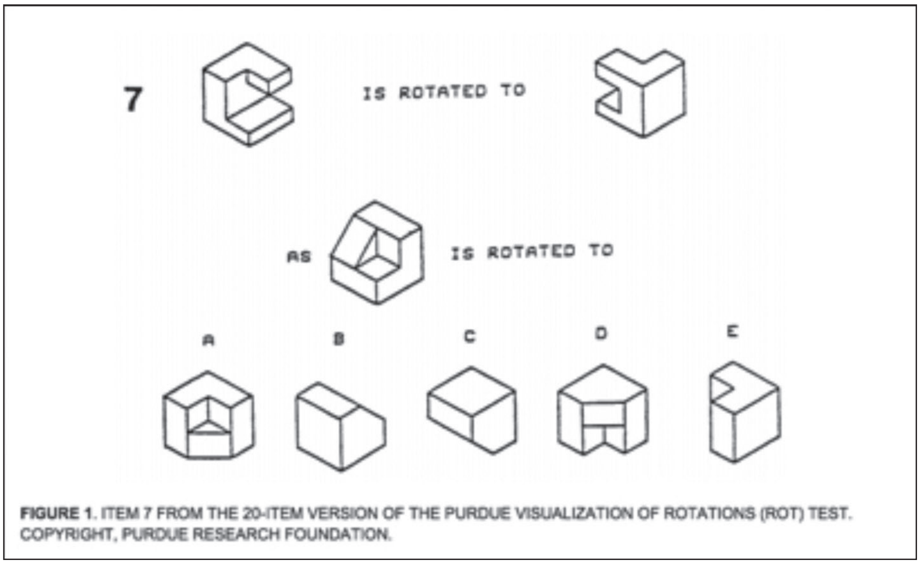

Figure 5. A problem from Purdue Visualizations of Rotations Test

we know them" (1999, p. 204). Within the STEM fields, in particular, there has been a significant push to further develop modeling and dimensional thinking with college-aged students.

At the Colorado School of Mines, a public STEM and applied science university, students are encouraged to enroll in a semester-long spatial visualization and rotation course. Through hands-on modeling exercises, students strengthen their ability to imagine, conceptualize, and rotate complex 3-D models. The ability to do so has been linked to heightened performance in future coursework and professional pursuits. As Hsi, Linn, and Bell noted, "spatial reasoning was significantly related to course performance…Spatial strategies contribute to success in many and prepare students for the wide range of professional activities" (1997, p. 157). It is not surprising, given the four types of models we have discussed (*physical, theoretical, functional, & imaginary*), that modeling is seen as being imperative to the STEM disciplines – whether it be machine design or molecular structure analysis. As the National Science Foundation (NSF) notes, "well-developed math and verbal skills are universally recognized as necessary for success in STEM and the National Science Board maintains that spatial skills should be added to this list" (2010). Research routinely shows that practice, especially ongoing, progressively sequenced and challenging practice, directly correlates with improved visualization and dimensional ability (NSF, 2010). Practice is especially effective and transformative among women and individuals from lower socioeconomic groups who tend to present lower initial ability with three-dimensional model rotation (Contero et al., 2006; Ferguson, Ball, McDaniel, & Anderson, 2008; Hsi, Linn, & Bell, 1997; NSF, 2010; Raif & Samsudin, 2007; Sorby, 2009, Towle et al., 2005). Practice and improvement with spatial visualization and dimensional thinking has also been correlated with stronger student self-efficacy (His, Linn, & Bell, 1997).

Spatial visualization and dimensional thinking support an individual's ability to manipulate and conceptualize an object with multiple angles, perspectives, and elements. Modeling calls on the same process and competencies. And given this, it becomes increasingly important to consider examples of modeling in teaching and learning contexts. Above we have provided some discussion of this in professional or higher education teaching and learning, but we would also like to examine this in K-12 contexts.

Modeling for Creative Education

We examine a few such classroom examples, based on work done by students (who are also practicing teachers) in our Masters in Educational Technology program at Michigan State University. In this program, we offer a course entitled "Creativity in Teaching and Learning", which focuses on developing both the personal and professional creativity of teachers through the lens of trans-disciplinary skills. In using these skills as a lens for creative teaching and learning, we aim to have our teachers work on integrating them into their own classroom practices and lesson designs. Our teachers create classroom artifacts, concepts and lesson plans based on trans-disciplinary thinking skills (like modeling), for a variety of classroom contexts and subject matters. We include a few examples below to give just a brief sense of this.

In our first example we look at the value of modeling as it was used in the teaching practices of a high school language arts teacher. As a student in the Creativity in Teaching and Learning course, this teacher discussed the importance of modeling for helping to communicate complex ideas her students might otherwise fail to grasp. She talked about the fact that her students often struggled to understand The Canterbury Tales, both in terms of the Middle English language structures used by Chaucer and in the political and social context of the characters in the medieval setting. She used modeling as the basis of a lesson that helped her students understand all of this better – by having students create models of the characters in the Canterbury Tales in their own modern version of these characters. She noted that the students came up with a "gold digger" for the Wife of Bath, a Marine for the Knight, a ladies man for the Squire, a college student for the scholar, and so on. She reflected on how modeling engaged student understanding of the abstractions in Chaucer's writing, saying that:

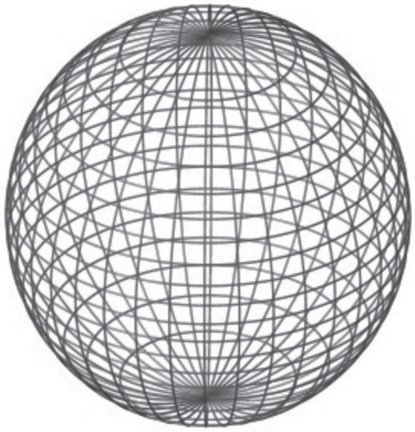

Figure 6. Wireframe sphere from applet

> As a class, we break down the Canterbury Tales for what it is - a list of the people representative to the time period, try to understand from a historical perspective why Chaucer may have pointed out different elements within the people representing the church, or the people from Guilds and the Feudal System and so on, and then we apply that understanding to what we know about people today. We create our own model of society through a Modern Retelling of the Canterbury Tales. This is then turned into a book of stories that we write, and compile, within the classroom.

Using the idea of modeling, she was able to have her students break down the elements of the characters, then discuss tone and characterization to determine whether the person is being admired or criticized, and what the author is trying to tell us. The modeling goes to an even deeper

Figure 7. Paper spiral

Figure 8. Evolving the paper spiral

level of understanding and creativity when the students then identify the voice of the author and create that voice for themselves in their own iambic pentameter and rhyming couplets – based on the model that Chaucer provides.

The second example that we share is from the field of art education. In this case, a high school art teacher wanted to help her students understand how models allow artist to formulate their ideas. During a unit on public art, one of the pieces in her curriculum was the sculpture Sphere (2003) by Danish-Icelandic artist Olafur Eliasson. This teacherx r modeling ax   cling to learn about solid construction. She had students begin byct that they could use to map, rotate, manipulate and learn about 3D modeling (see Figure 6)

From there however, she wanted students to learn about how to physically conceptualize a piece, and understand the elements of construction, balance, and how materials physically link together to form a complete piece. So she had them start out with a flat piece of paper, and then begin conceptualizing ways to make a sphere. They begin with a spiral – as shown in Figure 7.

Students soon were able to see that while the design was interesting, it needed some form of support in order to stand on its own (something that they don't get as strong of a sense of in theoretical or digital modeling). So they continued to evolve the design, again, as shown in Figure 8**.**

Again though, support was an issue. The students also realized that balance needed to be considered, as this sphere design was both physically and artistically (visually) heavy on one side. Finally, through the evolving process of modeling they were able to come up with something effective, as exemplified in Figure 9 on the opposite page.

In reflecting on the entire process of instituting modeling into an art lesson, this teacher noted how valuable the skill of modeling was (particularly physical models in the arts) for crafting a piece of work. She stated that,

> Without hands on experience, students would not be able to fully comprehend the designs they could generate in 3D graphics. Even working with inexpensive paper they will encounter issues of structural support, design flaws, balance, weight, etc., better than they otherwise could. These are all important steps in crafting a functional and neighborhood friendly piece of public art. Without modeling, structural and design mistakes would be costly and could potentially be dangerous.

The above two examples focus on non-STEM areas such as literature and the arts, but of course, as must be clear by now, modeling has a vital role to play in STEM fields, in creating representations of complex phenomena or understanding how things work. In one such example, one of our Masters level teachers taught a basic engineering design course for high school. She stressed the value of modeling for engineering overall, but particularly for the way that it allowed her students (who are just learning basic ideas) to engage in tinkering and understanding how things are made. She noted that, "For engineering students to understand the roots of technology sometimes they have to create a mock up and do reverse engineering to get to the basis of how and why things were created." This involves using Computer Automated Design (CAD) software to design mockups and test feasibility before resources and time are wasted in building.

She created a lesson in which students could use tiny mockups that let them create a product in a virtual rapid prototyping machine, showing gears. This modeling design task gave them an understanding of the product without the investment of time or money that more elaborate prototyping would. They were able to use animation to check for interferences, and do dimension checks with gears to ensure that the details were as needed. When constructing a model in CAD students were able to change errors at no cost, and go back and forth tinkering with details (e.g. how far apart the shafts of gears should be, or the pitch radius of both gears, or anything pertinent to their project). This teacher noted that,

> This understanding impacts my topic because for students to understand the roots of technology, they must also understand the design and modeling process behind their product. Engineers have a process they go through when designing new models of sketches (ideations), researching, CAD – and once that is done, they work and re-work things. The model is never quite complete.

Given this example along with the others noted, it is clear that modeling spans disciplines and contexts, and can be approached in different ways – using digital technologies, visual

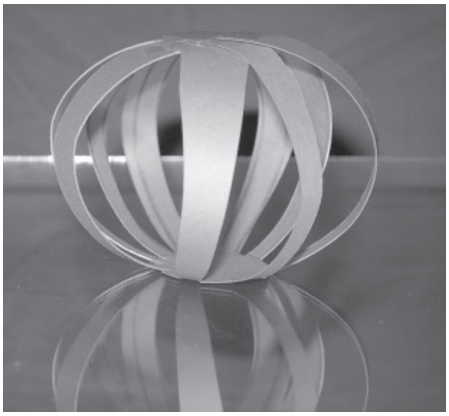

Figure 9. Final paper sphere

abstractions, or more physical tools for building. These are just a few examples of the power of modeling for creative and effective thinking in settings for teaching and learning.

Conclusion

One of the important aspects of modeling (and in fact all seven trans-disciplinary skills we are describing) is the manner in which they cut across the sciences, the arts, and the professions. A wonderful example of this can be found in the making of the recent Christopher Nolan science fiction movie "Interstellar". As it happens, the plot of the movie required the design and representation of gravitational worm-holes and a massive spinning black hole. One of the scientific consultants on the film, renowned astrophysicist Kip Thorne, criticized how black holes had been represented in previous movies, saying that, "Neither wormholes or black holes have been depicted in any Hollywood movie in the way that they actually would appear." The Director Chris Nolan and Kip Thorne (who was also executive producer of the film) wanted to change that. Subsequently, Thorne provided the animators with the fundamental equations of Einstein's theory of gravity and had them build their models from the bottom up. The visuals that show up in the film were then developed, from these equations, for a year by over thirty special effects experts. When Thorne saw what the animators, artists and computer scientists had developed he was shocked. It was completely different from the way he had envisaged it in his mind. In fact, he first believed the visual effects experts had gotten it wrong but then, on reflection, realized that it was his imagination of how these mathematical equations would play out, that had let him down; the images that had been developed were actually right. As Nolan said, "What we found was… we could get some understandable, tactile imagery from those equations. [The equations] were constantly surprising and it spoke to the maxim that truth can be stranger than fiction." From this experience, Thorne is now writing two scientific papers based on what he has learned about rotating gravitational black holes from his work in the film.

This example goes beyond the theoretical manipulation of equations by physicists, to show how the actual creation of the model through the collaborative efforts of scientists, artists and computer programmers, is what revealed the greater truth about how gravity functions under extreme conditions. It is an excellent example of the powerful role that the skill of modeling can play in learning.

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