An Inductive Approach to Digital Modeling Instruction

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Abstract

An argument is presented for respecting the student's process of inductive reasoning in introductory digital modeling instruction. The inductive education methods of Montessori and VanDamme are reviewed, and relevant portions are applied to the problem of digital modeling instruction. Two primary concerns are presented: 1) the need to systematically reorient the student from the physical world to the digital world and 2) the need to sequence the presentation of introductory concepts according to logical dependencies inherent in these concepts. Five principles of inductive digital modeling instruction are established, which could act as the basis for a teaching method that reduces alienation among apprehensive students, eases the transition from traditional media for veteran designers, and speeds comprehension of core concepts of digital making.
1 Introduction

As practicing architects recognize the power of digital modeling, its applications expand beyond the production of presentation renderings into the realm of design. What was previously the province of CAD technicians is now becoming a general architectural skill. This invigorated interest has created a surge of introductory digital modeling instruction both in academic institutions and especially among professional “CAD trainers.” As the focus of instruction shifts away from digital drawing to digital modeling, and as the digital modeling system becomes the tool of choice among practicing architects, better methods of modeling instruction are in demand.

Under pressure from this demand, academic and professional educators often build instructional methods on-the-fly, racing to meet the needs of a hungry population rather than developing a systematic approach based on sound educational theory. This paper argues that such grounding is important to effective introductory digital modeling education, and in particular, inductive reasoning theory provides the needed instructional foundation.

Regarding the research method of the paper, it is worth mentioning that no attempt is made here to validate conclusions through empirical experiment. While experimental verification is a worthy goal, the method used here is philosophical. Rather than test a hypothesis, the paper establishes a set of premises validated through common human experience or occasionally by reference to prior empirical studies. Conclusions are then drawn from these premises through the application of logic. In other words, what is presented here is an argument – specifically an epistemological argument – not the results of an experiment. The goal of the argument is not to validate a particular educational technique, but to establish a set of principles that could guide the development of a valid technique. Since Maria Montessori’s method is discussed later at some length, it is also worth noting that she too pursued an epistemological validation of her method, not a scientific one. Although she embraced the early twentieth-century fervor for scientific pedagogy, she believed the scientific method alone failed to provide sufficient guiding vision. In her words, “We start essentially from a method, and it is probable that psychology will be able to draw its conclusions from pedagogy so understood, and not vice versa” (Montessori 1964). Although the Montessori Method does include elements of technique, it is at root a philosophy of education – a precondition for the development of verifiable technique. While the scope of Montessori’s work is broad and ambitious, the present paper seeks to address a single issue in the philosophy of education and establish its relationship to digital pedagogy.

2 Background

According to the inductive theory of knowledge, all knowledge begins with sensory experience of the physical world. As children we form our first concepts directly from sensory experience of physical entities, and as our repertoire of sensory-level concepts grows, we integrate them to form higher-level concepts, which enable us to achieve greater degrees of abstraction from our sensory starting point. “Chair,” “table,” “bed,” and “dresser” are examples of sensory-level concepts. These concepts refer directly to something we can point at. The concept “furniture”, on the other hand, is a higher-level abstraction formed by identifying a similarity among chairs, tables, beds and other items. The even wider abstraction “tool” subsumes not only furniture, but a host of other useful things. Later generalizations such as “furniture” and “tool” follow from and are based upon earlier ones, creating a dependency among concepts. This means a higher-level concept cannot be grasped if the necessary lower-level component concepts have not yet been formed. The theory of inductive reasoning holds that concept formation progresses in stages from sense perception to less abstract concepts and finally to broader abstractions drawn from earlier concepts (Piekoff 1991).

This premise creates a pedagogical imperative. If there is a necessary order in the formation of concepts, then there is a necessary order in the presentation of concepts, which the teacher must not violate (VanDamme 2002). When a teacher presents a new concept before the student grasps underlying concepts, the student lacks the foundation needed for real understanding. The new concept can be described as “empty” or “floating” in the mind of the student. Left in such a state, the student can only memorize the new concept as a word without connection to other concepts or to sensory experience. An anecdotal but illuminating account of the undermining effect of “empty” concepts in childhood development is described by Feynman (Feynman 1999).

I first became aware of the need to follow a particular order in the presentation of digital modeling concepts by observing recurring points of confusion among students. I noticed that such confusion occurred at consistent points in my presentation. For example, after explaining the concept of the Working Plane and Object Snaps, many students continued to struggle when locating a desired point in space. The students seemed to...
inductive reasoning in an educational setting. She referred to age three to six is one of the earliest examples of formalized inductive method, there are explicit theories of inductive reasoning. When confusion arises. While such teachers implicitly accept the student's ability to select a point in digital space, I had neglected to explain how the Working Plane and Object Snaps work together to determine the point. There are of course circumstances where these two mechanisms contradict each other. If the Working Plane is located far behind a cube and the student snaps to the corner of the cube, the selected point could occur at the corner of the cube, or it could be projected onto the Working Plane beyond. It depends on which of the two mechanisms is dominant, and most modeling systems allow the operator to control this. After explaining the concept of a dominant point selection mechanism, and explaining how the student controls which is dominant, the confusion vanished.

Despite my good intention to guide students to real understanding, I sometimes skipped crucial concepts or introduced and relied on a concept before I had properly introduced it.

There are surely options in the order a mind can form concepts, and there is a vast collection of physical entities that provide the ultimate sensory basis for concepts. Consequently, there is a whole family of varied instructional sequences that respect the nature and requirements of inductive reasoning. However, as described in the example above, some approaches violate these requirements. The following argument establishes some principles to help instructors recognize such errors, and to shape a systematic method of instruction that respects the requirements of inductive reasoning.

3 Reorienting to the Digital World

3.1 Inductive Education Applied to Physical Laws

Many teachers recognize the need to present concepts in an order that facilitates inductive reasoning, but they resort to trial and error to find such an order. As I described in my experience with the Working Plane and Object Snaps, many teachers filter out errors by closely observing students and compensating when confusion arises. While such teachers implicitly accept an inductive method, there are explicit theories of inductive education. Maria Montessori’s approach to teaching children age three to six is one of the earliest examples of formalized inductive reasoning in an educational setting. She referred to this component of her method as the “Education of the Senses” (Montessori 1964). Montessori works from the premise that a child’s progress in forming sensory-level concepts of material properties such as color, hardness and weight is substantially enhanced by filtering and systematizing the child’s exposure to objects possessing these properties. The earlier prevailing attitude was that formation of such basic concepts in the child’s mind happens automatically, just by virtue of perceiving the physical world. A similar strain of educators today believe a student “picks up” digital understanding just by virtue of exposure to digital tools (Nicol 1990). In this view, if we just give students the tools, they will figure it out on their own. Montessori discovered that this is not true in the physical world, and as we shall see, it is not likely true in the digital world either.

A more recent innovator in inductive education Lisa VanDamme of the VanDamme Academy in Laguna Hills, California, is developing an inductive education curriculum for fourth through seventh grade. Her method builds on the foundation of sensory-level concepts attainable with Montessori’s Education of the Senses, and extends beyond these concepts to higher-level concepts of gravity, friction, mechanical advantage, air pressure and so forth (VanDamme 2002).

Both Montessori and VanDamme emphasize the need to isolate and reduce to direct perception each material property or natural law. The student does not just read about the force of friction and how it produces heat as a byproduct, nor does he merely learn to manipulate an equation that calculates the amount of heat produced. The teacher never asks the student to accept any behavior of nature on his authority. Instead, the student directly witnesses and measures the phenomenon.

The mechanism by which this happens is an educational experiment. In the Education of the Senses, Montessori uses a “didactic object” to isolate a material property for study. In one experiment the child is confronted with a peg board containing holes of graduated diameter, and a scattered collection of pegs with equivalent graduated diameters. The child solves the problem of matching peg diameter to hole diameter. In another peg board experiment, the board contains holes of equal diameter but varying depth. The pegs have a corresponding graduated set of lengths (Montessori 1964). Van Damme uses a similar series of experiments, though more elaborate, to isolate and study the behavior of physical laws. Other test experiments, require the student to evoke already formed concepts to explain a newly encountered phenomenon. For example, at the conclusion of two separate series of experiments on friction and air pressure, the teacher wets the rim of a plunger, pushes it against the top of a stool, and then lifts the stool into the air using the handle of the plunger. This is followed by the question, “Why did this happen?” Although the students have not previously seen the experiment, some offer sophisticated explanations that integrate the concepts of friction (as viscosity) and air pressure (VanDamme 2002), and without prompting from the teacher.
3.2 Inductive Education Applied to Digital Laws

Most of us learn digital modeling in the context of architectural design only after reaching adulthood. And many veteran architects are still acquiring this skill later in life. This means the student of digital modeling has a fundamentally different context of knowledge from that of a child. He has already formed many high-level concepts of the physical world and its behavior. But in another sense, the student of digital modeling is not so different from a child. A child must learn the fundamental concepts of the physical world, and the student of digital modeling must learn the fundamental concepts of a digital world. Since a digital world operates according to its own rules, which do not necessarily correspond to the laws of nature, the student of digital modeling is set again in the state of a child experiencing a world anew. He must build an understanding of digital laws in the same way he did of physical laws, starting with fundamentals and building upon them gradually through a process of inductive reasoning, ultimately tied to direct sensory experience.

Yet digital modeling instruction cannot proceed as if the student is a child. The student has a vast experience of the physical world that is not forgotten when he enters the digital realm. For this reason the process of inductive reasoning undertaken by a student of digital modeling is more difficult than that of a child experiencing nature. Not only must the student acquire digital concepts in a proper sequence, but he must also integrate digital concepts into an existing body of knowledge based on his experience of nature. If digital concepts are not related back to what is already known and familiar in the physical world, these new concepts remain alien for a long time and undermine the student’s chances for educational success. Yet, if a mental connection can be made between newly encountered digital laws and familiar physical laws, alienation quickly diminishes (Erickson 1990).

It is instructive at this point to introduce some examples of differences between physical laws and digital laws, in order to illustrate how these differences influence the student. My examples are drawn from the capabilities of Bentley Systems MicroStation, which is the modeler I use in introductory instruction. However, the issues discussed here apply to most or all mainstream modeling systems.

The first example is gravity. Gravity does not exist in MicroStation, nor is it simulated in any mainstream modeling system available today. Yet gravity is deeply connected to the human way of grasping spatial orientation and the relationships among objects in the physical world (Templeton 1973). The student must understand the consequences of operating in a gravity-free environment, and why an alternative means of spatial orientation is needed. The student has lived his whole life relying on gravity to assist spatial understanding; hence the absence of gravity in the digital realm fundamentally undermines his ability to comprehend digital space. However, we do use other means to achieve spatial orientation in the physical realm. The most important of these is visual perception of horizontal and vertical (Prinzmetal and Beck 2001). Establishing this visual frame of reference again makes basic orientation concepts such as “up” and “down” meaningful. In digital space, a horizontal and vertical reference, because it can be depicted visually, is easier to achieve with current technology than simulated gravity, and this visual reference is the main way spatial orientation happens in digital space. Because it functions alone, the horizontal-vertical reference is crucial, and if a student does not understand how to find and use this reference, much of what happens in digital space remains unintelligible. Thus, the student must adjust his habitual orientation paradigm to remove the reliance on gravity and replace it with a heightened awareness of the horizontal-vertical visual frame of reference. This adjustment is not automatic. It requires explanation and practice in the form of focused exercises.

A second example is our tactile sense. The highly developed sense of touch in the human hand is highly developed and provides precise feedback about the surface qualities of objects (Derevensky 1979). Using the hand in combination with the eye, we gain even greater precision, identifying the location of minute deviations on a surface or shape (Klatzky and Lederman 1987). We learn the feel of an object edge versus an object face, and by adulthood this means interaction is thoroughly integrated into our spatial paradigm. Yet this basic means of interacting with objects is stripped from us in the digital realm. As in the physical world, we must “touch” digital objects often in the process of building a model. We select objects and we locate precise edge and corner conditions. In current mainstream computer hardware, since tactile feedback is more difficult to implement than visual feedback, the student is asked to make a crucial substitution. His tactile sense is replaced by graphic feedback such as object highlighting (for selecting) and cursor events (for locating precise geometric conditions such as corners or edges – i.e., snapping). This substitution is no less fundamental than the gravity substitution described above, and the student must adjust his basic spatial paradigm accordingly. This adjustment is not automatic. It requires explanation and practice in the form of focused exercises.

It is important to note that these examples might not always be relevant. It is reasonable to project a future where computer hardware and modeling software simulate gravity, touch, and a host of other physical properties and laws. A more thorough simulation of nature might be a hindrance, though, since it could undermine the potential of digital modeling to surpass the limitations of the physical world. New and radically different digital worlds become increasingly possible, and such worlds might open exciting creative possibilities.

The point here is pedagogical, not technological. Until we have holographic chambers in the spirit of Start Trek, or brain links into virtual worlds in the spirit of The Matrix, there remain differences between the laws of the digital world and those of nature. (In fact, this is true even in Star Trek and The Matrix.) And to the
extent these differences exist, the inductive starting point for digital modeling education must be to bridge this divide – to provide a way for the student to systematically adapt his habitual physical world paradigm to one appropriate to the digital world of his choosing.

Notice that inductive education is vital to the development of radically different digital worlds. If advances in computer technology serve the goal of natural simulation, then eventually inductive education, at least in its role described here, becomes obsolete. Yet when a student is confronted with a radical departure from nature, an inductive approach is crucial. For it is here that a digital world is most alien, and the student is most in need of the teacher’s assistance bridging the conceptual differences, thus enabling his knowledge of a new digital world to integrate with an existing body of physical world knowledge. In other words, the more a digital world differs from nature, the more important it is for the teacher to explain the differences. Only this can make the digital intelligible.

The increasing attraction of spatial computer games among the young erases some aspects of this divide by the time such youngsters reach adulthood and begin design education. Particularly at the level of basic digital perception, early exposure to digital worlds could ease the adult’s transition into a design system. In fact, because of the age of its customer, the computer game industry is more sensitive to the issue of digital reorientation than most developers of mainstream design systems. This heightened sensitivity reinforces the point that regardless of where the reorientation happens – in the games of childhood or in the design systems of adulthood – the reorientation must happen. And despite some useful similarities between games and design systems, it is unlikely that the former will become a complete tutorial for the latter. The designer generally requires a more sophisticated control over digital space and its objects than a child enjoying a digital adventure.

4 Respecting the Conceptual Hierarchy

After the student has adjusted his habitual means of interaction to accommodate the unique laws of the digital world, he is prepared to learn about the many capacities of this new world, gradually expanding his digital knowledge. Here the process of inductive reasoning is equally important. The central concern for the teacher is the order of concept presentation, which must respect the logical hierarchy inherent in any body of knowledge. In the following section an argument is made for a particular order of presentation, emphasizing its logical necessity and noting some common problematic deviations.

The subtly different capabilities in mainstream modeling software result in possible variations in the sequence of presentation. What is described here is a wider conceptual framework that applies more broadly. It establishes a standard of evaluation that can be used to identify an inductively valid presentation order, or to identify induction errors in an existing presentation order.

The first concept in the framework is *Perception*. Before we can take any purposeful action in the digital realm, we must know that the realm exists and we must know at least something of its nature. We must establish contact with the digital world through some type of conscious awareness. This awareness can take any form, from pressure-controlled gloves to audible tones produced by a microphone, but it must take *some* form. Without a way to perceive what is happening in digital space, we cannot act purposefully. The most common means of perceiving digital space in mainstream hardware and software is of course the graphical display, which combines the computer screen with the concepts of Window, Viewpoint and Camera. We see a representation of digital space through a Window, which always inhabits the plane of the screen. The particular portion of digital space displayed defines our Viewpoint, and we control our Viewpoint within the Window by means of a Camera (or Eye Point) location. Unlike the Window, the Camera inhabits digital space.

The order of presenting the concepts of Window, Viewpoint and Camera might be optional, and in fact, these concepts might eventually become obsolete, but some means of perceiving digital space is necessary, and the student must understand what his means of perception is and how to control it. Before any other meaningful digital actions are possible, he must first open his digital eyes and look around.

The second concept in the framework is *Position*. Establishing a position in digital space is a second precursor to purposeful action, since a modeling action is not purposeful if it occurs at an arbitrary location. Positioning is the process of identifying a desired point in space. It requires a means of transposing a point selected on a flat screen with a pointer to some position within the volume of digital space. Two mechanisms used to accomplish this in mainstream software are the Working Plane and the Object Snap. A Working Plane allows access to the depth of space by transforming the plane of the screen to a location in space, which then allows a screen point to be projected onto the plane. Object Snaps allow a screen point to be projected onto identifiable parts of an object’s geometry, such as corners and edges.

The order of presenting the concepts of Working Plane and Object Snap might be optional, and surely other means of spatial positioning will be invented, but whatever the means of positioning, it must be presented *after* the means of Perception described above. A position is only meaningful to the extent one is aware of it. Providing a student with a means to determine a spatial position without first establishing the means by which that position can be understood and verified through perception makes the act of positioning unintelligible.

The third concept in the framework is *Transposition*. This is the act of moving, rotating or otherwise altering the position of a digital object. Transposition involves a number of sub-concepts such as Direction and Distance. In order to move an object,
for instance, one must determine which direction to move it and how far. This might involve any combination of reorienting or repositioning the Working Plane, Snapping to various points on objects, or keying in numbers. Regardless of the mechanism used, a Transposition requires the identification of two points in space, a start position and an end position. These two positions constrain both the direction and distance of the Transposition action. And thus, Transposition relies on the concept of Position. Without first knowing how to locate one position in space, a student cannot comprehend how to locate two positions. Even a simple alteration of the Working Plane – moving it from one location to another – presupposes the concept of Position. The first three concepts in the framework might seem self-evident. These three stages of digital understanding are so fundamental that deviating from the order described above is often catastrophic. The common teaching error made in these early stages is the omission of concepts, rather than an inversion of sequence. Those who teach digital modeling are often advanced practitioners, and they take for granted many of these early steps in the learning process. They have long forgotten their own experience learning these things, and they come to believe such concepts are obvious. Yet such fundamentals are only obvious to the expert after study, practice and habit formation. Especially with Perception and Position, it is common practice among professional CAD trainers to race through these concepts as though it is a review of something already known, and students proceed from the beginning with an incomplete foundation upon which to build.

The fourth concept in the framework is Creation. This is the act of making a new object out of nothing. The most basic way this happens is by generating a primitive geometry such as a cubic solid, sphere or cylinder. Creating a primitive requires an understanding of the geometric nature of each primitive, and the kind of information needed by the modeling system to define it. For example, a cubic solid usually requires the student to designate four points in space, one defining its general position, which acts as the start point for creation, and then three more points to define height, width and depth. A cylinder, by contrast, can be defined with three points – start position, radius and height.

It is easy enough to see how Creation presupposes Perception and Position. A student cannot comprehend object Creation without first being able to perceive objects and locate the points in space required to define a new object’s position and extents. The fact that Creation also presupposes Transposition is not obvious, and this is a point in the inductive chain often breached. Many fail to recognize that Creation is almost always a two step process. In its most basic form it is as follows. First, move the Working Plane to the location where the new object will be made, and then second, make the object. This process requires the student to already understand the process of Transposition as applied to the Working Plane. An alternative method is to first make the object at any convenient location, then as a second step, move it to where it belongs. This method is necessary because it is often difficult to position a new object directly as desired during the process of defining geometric extents. This second method, too, relies on an existing understanding of Transposition, since the object must be moved into place after Creation. Without understanding the relationship of Creation to Transposition, purposeful Creation is undermined.

The tendency is to place Creation too early in the instructional sequence, sometimes even before Perception and Position. The usual thinking is that one must first create something before one can learn how to view it, to locate positions on it, or to move it. The decision to place Creation first follows directly from the way one uses most mainstream software – first one makes a new file, which is empty, and then one makes an object in the file. However, the order of operations used in software to perform work is not always commensurate with the order of concept presentation needed to grasp the nature of the work. The indiscriminate alignment of learning procedure with software procedure in this way undermines inductive learning.

In response to the Argument for Creation First – i.e., that objects must be created before Perception, Position and Transposition are possible – I would answer as follows. Objects must exist, but the objects used to demonstrate these earlier concepts do not need to be created by the student. One implication of the framework defined here is that in the early stages of learning a student should never encounter empty digital space. When learning to perceive the digital world it must be richly populated with things to perceive. When learning concepts of Transposition, there must be a dense field of existing objects for the student to “play with.” Consider Montessori’s peg board experiments. The child is given a provocative set of objects as a starting point. If Montessori had expected the child to make the pegs himself before learning basic concepts of size and shape, the inductive chain would be inverted and the child would be dumbfounded. How can the child make pegs of incremented lengths before he grasps the concept of length? Expecting a student to learn the process of object Creation before Perception, Position and Transposition is equally devastating to effective learning.

The student should never confront the disorienting void of unpopulated digital space until he masters all the basic concepts described here. Even when learning the process of Creation, the student should always make new objects in the context of a provocative digital environment inhabited by other objects, which is pre-established by the teacher.

5 Conclusion
In summary, we may distill from the above argument the following five principles, which support inductive digital modeling instruction.

- The first task is to reorient the student from the physical world to the digital, by showing the differences in world
behavior. The more a digital world differs from nature, the more important it is for the teacher to explain the differences explicitly and systematically, and to allow the student to experience the differences directly through practice. Only this can make the digital world intelligible to a being that inhabits the physical world and necessarily uses it as context.

- Each concept must be isolated for study and practice by a precisely constructed educational experiment that allows the student to perceive the referents of the concept directly.
- The student should be given ample time to adjust (through focused practice) his physical world habits to account for the different characteristics and behaviors of the digital world. This process is often slow and difficult for the student, despite often seeming self-evident to the expert.
- After the student has successfully adjusted his orientation and interaction habits to the requirements of digital life, the central concern of inductive digital modeling instruction is the order of concept presentation, which must respect the logical hierarchy inherent in any body of knowledge. Respect the general order of Perception, Position, Transposition, and Creation. Resist the tendency to place Creation too early in the presentation sequence.
- The student should never confront the disorienting void of unpopulated digital space until he has mastered Perception, Position, Transposition and Creation. Instead, he should always encounter a pre-populated world of compelling objects, just as a child does in his first experiences of nature.

References


