

# Genuine Object Oriented Programming

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A.B., Computer Science  
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SUBMITTED TO THE PROGRAM IN MEDIA ARTS AND SCIENCES, SCHOOL OF  
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## **Abstract**

Genuine Object Oriented Programming (GOOP) pushes Object Oriented Programming into the physical world. It is an integrated physical and computational construction kit in which children can use new “Things That Think” technology to build interactive communities of computationally augmented objects. GOOP provides an environment for children to explore and expand their own “Theories of Mind”, allowing them to construct powerful ideas about the nature of metaphor and shared understandings. GOOP makes this exploration engaging by allowing students to create and participate in physically instantiated “interactive fantasies” involving multiple characters, objects, and places. Novice students can gain access to GOOP’s power by initially interacting with its components at a high, metaphorical level, and then incrementally building their understanding through object deconstruction.

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# Genuine Object Oriented Programming

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# 1: Introduction

*When you first glimpse Dr. LEGOHead, (see Figure 1), he looks a “LEGOized” version of his namesake Mr. Potatohead. Like Mr. Potatohead, he is predominantly a head with places to attach other parts, such as eyes, mouths, and glasses. The difference between the two creatures becomes apparent when you start attaching parts to “The Doctor”. Unlike Mr. Potatohead, the Doctor behaves differently depending on how you manipulate his parts. For example, if you start out by putting the Doctor’s left eye in his right eye socket, he generates a “bloop” sound that suggests that you have done something wrong. If you move the eye to the correct socket, the Doctor beeps in a more affirming tone.*

*When you attach the mouth, the Doctor suddenly starts speaking and can respond verbally to your interactions with him. He responds differently depending on what expression you gave him, however. If he is smiling, he will respond to your actions in a cheerful fashion: put his eye in the wrong place, and instead of just blooping, he will say “Nice try, but you put my right eye in my left eye socket” If he is frowning, however, he will respond angrily, exclaiming “Ouch! That hurts.”*

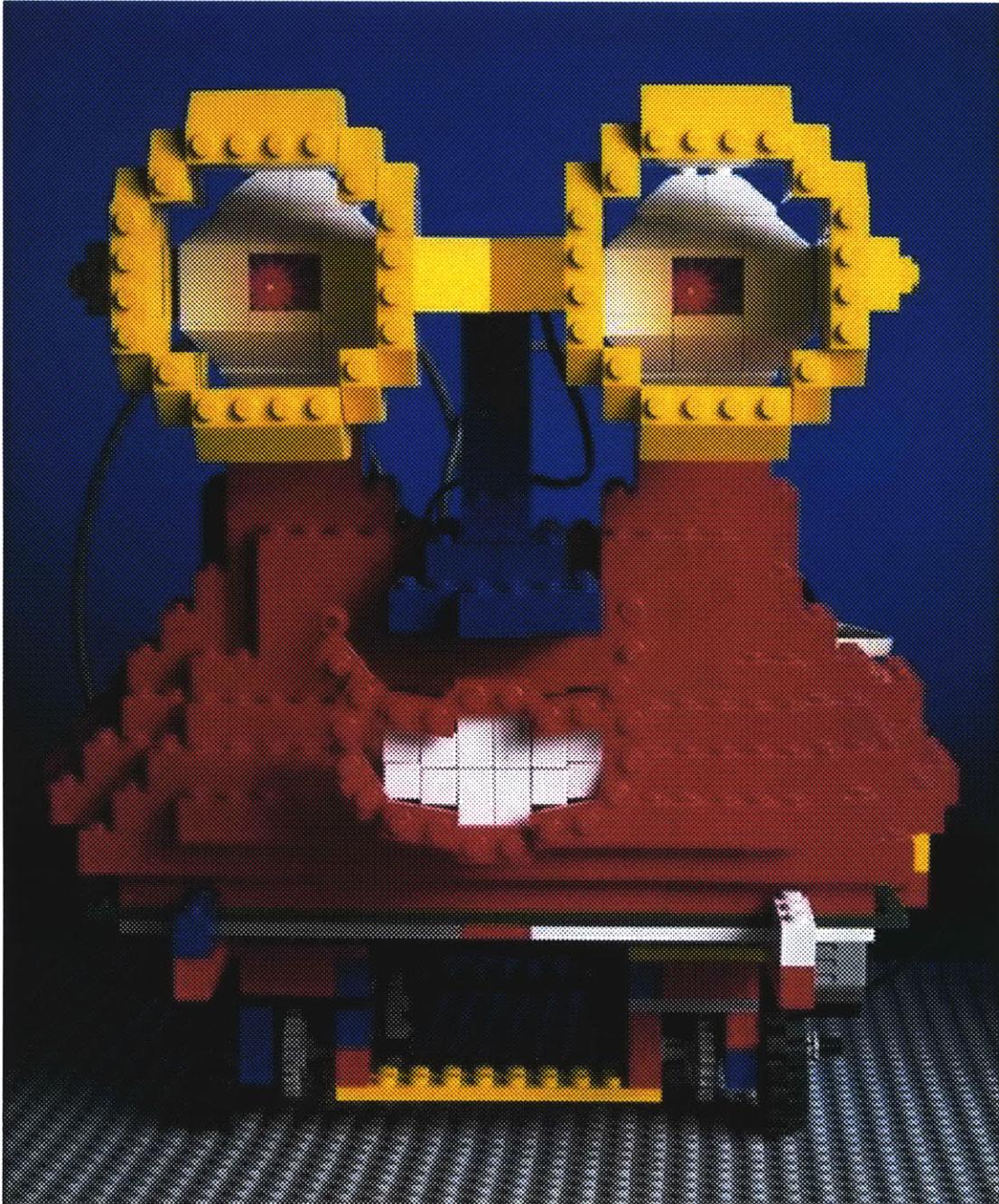
*Not content to be a just a toy himself, the Doctor has his own toys to play with. Snap a picture of him with his camera, and his vain side comes to the surface. Immediately, he will object if he is not smiling. Turn his frown to a smile, take a few more pictures, and the Doctor will react to every flash: “Which is my better side?” he asks as he shows his left profile and then his right; “I don’t want my nose to look too big!” he exclaims while backing away from the camera. Put away the camera, take out the disco set, and the Doctor switches into Saturday Night Fever mode: as you control the strobe light, the Doctor dances the Hustle and sings his favorite disco lyrics.*

## 1.1 Research Goals

Genuine Object Oriented Programming (GOOP) is an integrated physical and computational construction kit in which children can build interactive communities of computationally augmented objects using new “Things That Think” technology (MIT Media Lab 1995). By pushing Object Oriented Programming into the physical world, GOOP allows students to build physical “Genuine Objects” that have both functional and symbolic properties. GOOP addresses two research questions:

- Can a constructionist environment be built that allows students to reflect on and expand their own “Theories of Mind?”
- Can such an environment be accessible and engaging to children?

Figure 1: Doctor LEGOHead



## 1.2 Introduction to Theory of Mind

Research suggests that around the age of three or four, children begin to develop a “Theory of Mind”, sometimes called a folk theory of mind, which is defined as “the ability of a person to impute mental states to self and to others and to predict behavior on the basis of such states” (Leslie 1987, p. 421). A Theory of Mind is what allows a person to make sense of the actions of others in terms of their beliefs and desires, and to structure his or her own actions in ways that will be understandable by them. Development of a Theory of Mind is considered crucial for healthy and effective social interchange; in fact, it has been hypothesized that a main feature of autism is a child’s lack of a developed Theory of Mind (Leslie 1987).

Research has been conducted on how children formulate their Theories of Mind, and some research has tied this formulation to imaginative play with toys (Singer 1994). However, very little work has been done on how a toy or other children’s environment could be explicitly designed to help children construct their own Theories of Mind. This is a good application for a Constructionist environment: an environment designed to provide students with the appropriate physical and computational materials to construct for themselves a set of powerful ideas (Papert 1991).

## 1.3 GOOP and Theory of Mind

Sometime after they learn to talk but before they begin formal schooling, children come to display a new understanding of perception, action, and talk that is symptomatic of a new sensitivity to a life of the mind. Children begin to recognize themselves and others as “things which think”... (Olson et al. 1988, p. 1)

If children are starting to think about the world as a collection of “things which think”, a collection of manipulable “Things That Think” should be a powerful object for them to think about the world with. Constructionist environments like LEGO/Logo already offer some of this capability (Resnick and Ocko 1991). As will be discussed later, such environments’ physicality, and their ability to support creations with some computational agency, make them good

environments for thinking about thinking. Three additional features of GOOP make it especially suited to children's constructions of Theory of Mind ideas, however:

**GOOP facilitates building a community of thinking things.** A environment designed to foster construction of Theory of Mind ideas should contain “computational minds”, such as Dr. LEGOHead, that the student can manipulate and explore. It should also allow for the construction of multiple objects that are “knowable” to both the student and the Doctor, such as the Doctor's camera and disco set. GOOP is optimized to help students construct just such a community of interacting Things That Think. Although far more impoverished than a community of real people, a community of Things That Think benefits from being more explorable and manipulable.

**GOOP objects have high-level world knowledge.** In order to encourage students to reflect on what characters like the Doctor know about their world, and to reflect on their own knowledge, the Doctor's world knowledge should be at a level that is familiar to them. Like humans, the Doctor recognizes and responds to familiar objects, not to sensor values. He can “think” about his own state in a way similar to how a student might think about it: according to meaningful objects and locations, not abstract numeric values and port identifiers.

**GOOP facilitates constructing objects with both symbolic and functional qualities.** Children already build Theory of Mind ideas through play with symbolic toys like action figures and dolls (Singer 1994). Very few of these toys have any agency of their own, however, and none allow this agency to be programmed by the child. GOOP allows children to construct symbolic toys with behaviors that can then function autonomously, allowing children critical distance to reflect on the “minds” of their creations. Also, GOOP makes both function and symbolism very salient, so children can consider the role symbols play in how we make sense of an object's function.

## 1.4 Thesis Overview

The key element of GOOP that makes it useful for children's construction of Theories of Mind is the “genuine object”. Chapter 2 introduces the basic features of the genuine object, a physical

object that integrates function and symbolism, such as the Doctor's camera. This chapter introduces genuine objects as whole entities, but their power comes from the fact that students can construct them and deconstruct them.

It is through producing genuine objects that students can explore the powerful ideas relating to the Theory of Mind discussed in Chapter 3. However, when students start out working in GOOP, they will most likely be consumers of genuine objects, not producers. By using genuine objects created by others, students gain access to their functionality without having to gain a deep understanding of their inner workings. The ways that this makes GOOP a more accessible and engaging construction environment are discussed in Chapter 4. As students start wanting to modify the behavior of these objects, they can begin to deconstruct them by examining their underlying mechanisms and making small changes. This will help students move slowly toward producing their own genuine objects.

## 2: The Genuine Object

*In the Spring of 1996, I showed Laura Allen, a student at the Harvard Graduate School of Education, my work on GOOP. She was very enthusiastic, and suggested that GOOP might be useful in a project she had been doing over the last year with nine fifth-grade girls at the Hennigan Elementary School. The girls had decided to build a “City of the Future” out of LEGO and Programmable Bricks (Martin and Resnick 1993). Work was well under way on the buildings and vehicles in the city, but the girls felt there was something missing: they wanted a robot tour-guide that could talk about the different city structures, tell who made them, and what purpose they served.*

*With only a month to go before the girls were scheduled to show their city publicly, I met with them at the Hennigan School to show them Doctor LEGOHead, and his female colleague Professor LEGOHead (see Figure 2). The Professor is a little different than the Doctor because her facial expressions can be changed by program control. For example, on command her mouth can rotate from a smile to a frown, and her eyes can look left and right. They really liked the Professor, and thought they could repurpose her parts and functionality to build a tour guide. Two of the girls, who I’ll call Maria and Adrianna, decided they would specifically like to work on this project.*

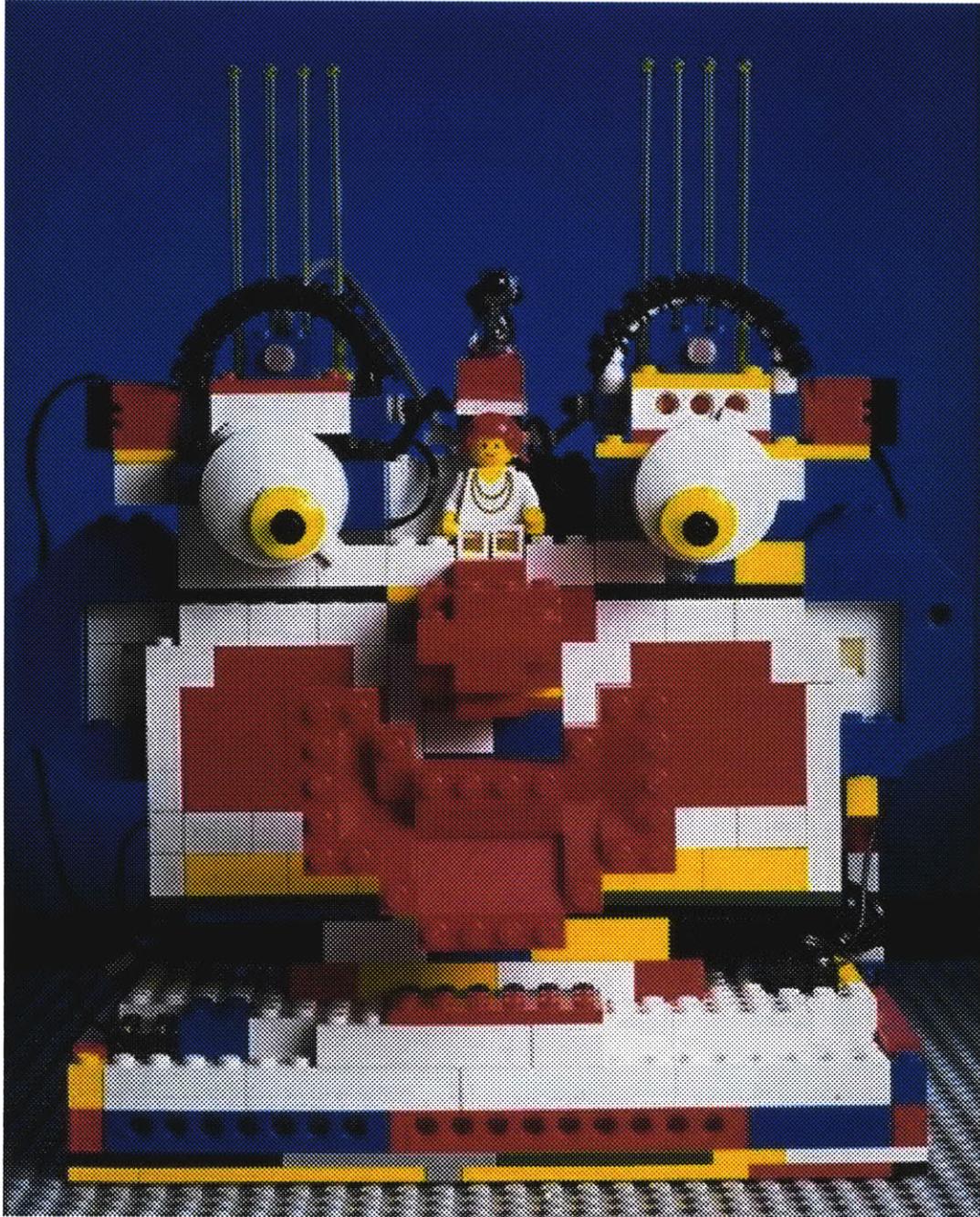
*They felt very strongly that the tour guide should be bilingual, since they were from a bilingual class at school, and many of the visitors to the city (such as their parents) might speak only Spanish or only English. We discussed how visitors might “tell” the Professor in what language they wanted to be addressed. Having seen the Doctor, the girls suggested that perhaps a city visitor could attach different mouths to the Professor depending on what language they wanted. Although they seemed to have a sense that a Spanish mouth was different looking than an English mouth, they were not sure how to articulate this in LEGO. They briefly considered creating different hats to represent the different languages, but again, neither girl was sure what the hats should look like. Finally, they hit upon the idea of using flags: if the visitor attaches a Mexican Flag to the Professor, she would speak in Spanish. If the visitor attaches an American Flag, the Professor would speak in English.*

*Together we built up a scenario where buildings and vehicles in the city would be turned into genuine objects simply by putting small infrared devices in them. A visitor would be able to express interest in one of these places by waving a “magic wand” over it, resulting in the Professor giving a little talk about the object. The girls built this quite simply by putting the “eye” that the Professor normally used to recognize objects at the end of the wand. Now the eye could go to the object, rather than visa versa. The kids then attended to the evocative nature of the wand, decorating it with glitter and paint to give it a magical quality.*

*Finally, I constructed an ear genuine object for the Professor that allowed the kids to record two pieces of their own speech, one in Spanish and one in English, for each genuine object in the town. When they attached the ear and started speaking, their speech was associated with whatever object the wand was pointed at, in whatever language was represented by the currently attached flag. When they pulled the ear off, the Professor stopped recording their voice.*

*On the day of the big show, the “Nine Techno Girls City” tour guide worked quite well. When a visitor pointed the magic wand at the Swan Boat, the Professor gave him a brief explanation of who built it and why. When he changed the Professor’s flag to the Mexican Flag, he got the same narration in Spanish.*

Figure 2: The Professor



This chapter describes the basic nature of genuine objects, while saving much of the discussion about their affordances to Chapters 3 and 4. Genuine objects are the cornerstone of Genuine Object Oriented Programming, which pushes the concept of Object Oriented Programming (OOP) into the physical world. Programming here has two meanings. First, users of GOOP constructions can program their behaviors by physically manipulating their parts, like the way the flag objects are used to choose a language in the Nine Techno Girls City, or the Doctor's mouth is used to control whether he can speak and what "mood" he is in. The other meaning of programming is the way students can construct GOOP objects through a tightly integrated mix of manipulating physical and software components. For example, the girls built the flags by associating small pieces of a Logo-based programming language (Papert 1980), called GOOPLogo, with the flag genuine objects; this code would automatically run when a flag was attached to the Professor.

GOOP appropriates two main capabilities of OOP: the ability to encapsulate complex functionality in an object with a simple interface, and the facility for easy object interaction through message passing. Other object oriented concepts, such as inheritance, could be useful, but are not currently implemented. The following sections explain the main object oriented capabilities of genuine objects. First, however, I will explore the importance of the physical nature of genuine objects.

## **2.1 The Value of Constructing Physical Objects**

The following paragraphs introduce a set of affordances of GOOP that arise from its physical nature, such as experiential richness and intersubjectivity. The combination of these affordances is currently hard to achieve in a virtual environment. The set of other GOOP affordances discussed in this thesis are not as unique to the physical world. However, because the first set of affordances makes GOOP more engaging and accessible (see Chapter 4), it greatly amplifies the power of the second set.

Real world construction kits, such as LEGO/Logo, have recognized costs and benefits in relation to their on-screen peers. Building in the real world still offers a much richer multi-sensory

experience than any purely computational world. However, the real world is “messy”, and therefore hard to control. Purely computational environments can put layers of abstraction between this real-world disorder and users, allowing them to focus on higher order concepts, rather than low level implementation details. However, these same layers of abstraction become impediments to the kinds of direct experiences and rich interactions that the physical world can offer. For example, the fact that all screen objects can be manipulated using the same physical mouse device, and that this interaction feels the same no matter what the object, is simultaneously enabling and distancing.

GOOP uses computation to help abstract away some of the complexity of constructing in the real world, without sacrificing the physical world’s experiential richness and tangibility. For example, with a construction kit, students frequently want to build things that are responsive to their environment. In a purely computational medium, this is usually straight forward, since the virtual environment is accessible as well-structured information. With a real world construction kit, information about a construction’s environment must be apprehended by the construction through sensors. These devices, such as a light sensor, have traditionally brought the student face to face with the messiness of the world, producing values that are erratic and hard to interpret. Instead, GOOP uses imbedded technology to create higher level “object sensors”, capable of reliably recognizing entire objects, like the girls’ flags. This allows students to build interactive real-world constructions with all their experiential appeal, while working at a level of abstraction usually reserved for purely computational media. I will explore this further in the section on genuine object interaction.

GOOP’s real world object sensing affords something even more powerful than the ability to create real world constructions at a higher level of abstraction; it also affords the illusion of intersubjectivity, or a shared understanding, between GOOP characters and an audience. This happens because the audience can see a character, such as the Doctor, looking at the same object they are looking at, such as the disco set, and they can see the character reacting to it the way they

might react to it. Much more will be said about the value of this later. For now, I simply want to highlight this illusion of intersubjectivity as an affordance of GOOP's physical attributes.

Finally, GOOP's ability to locate complex computational processes in physical objects resonates with users' tendencies to conceive of complex processes in terms of objects (Lakoff and Johnson 1980). This was one of the motivations for the physical nature of the original Logo turtle. When the turtle was later abstracted into a virtual object with greater capability, there was a sense that something important had been lost. This is because if one is trying to build an environment that makes the abstract concrete (Papert 1980), there is nothing more concrete than a physical object. Consequently, LEGO/Logo was developed, which reinstated turtle-like objects in the real world. GOOP continues in this direction by attempting to expand the abstract dimensions of its reified objects, while still maintaining their physicality.

## **2.2 Genuine Object Encapsulation**

GOOP allows students to build objects with both a symbolic and functional component. Furthermore, the mechanism that drives a genuine object's function can consist of both computational and physical (e.g., motors and gears) elements. GOOP's ability to encapsulate these multiple dimensions in a physical object is patterned on OOP's ability to encapsulate computational procedures and data in an easily accessible software object. The following sections explore the basic features of GOOP encapsulation, ending with a section on how GOOP specifically encourages students to consider both the functional and symbolic dimensions of a genuine object.

### **2.2.1 Encapsulating Physical and Computational Mechanisms**

When a child puts the Professor in her car, the Professor can then move around. The Professor's car encapsulates two construction dimensions. First, it encapsulates some physical mechanics in the form of motors and a complex gear train. However, this type of mechanical encapsulation alone would be insufficient to provide a simple software interface to the car; instead, a student would have to know a lot about these mechanics in order to successfully program the car

to move. Therefore, the car also encapsulates some computational ability, in the form of procedures written to make it go. Procedures like “Forward x” and “Right x”, which move forward and turn right for x seconds respectively, can encode the knowledge required to control the car’s motors and gears to achieve the specified behavior. When both the physical and computational mechanisms required to make the car work are encapsulated together, the car becomes usable in many new ways. For example, cars with entirely different steering mechanisms built by different people can be plugged in to the Professor, as long as they use the same standard primitive names.

GOOP’s facility for the encapsulation of physical and computational mechanisms into unified construction components differentiate it from LEGO/Logo, whose very name suggests that all the construction pieces are either LEGO *or* Logo. Even as LEGO/Logo evolves, the separation between dimensions continues. In an effort to scaffold the construction of complex LEGO mechanisms, Fred Martin has built up a set of frequently used LEGO Technic sub-assemblies, each of which encapsulates the interaction of many mechanical pieces in larger size granules (Martin 1995). At the same time, other members of the Epistemology and Learning group have been working on a LEGO/Logo programming environment called LogoBlocks that employs graphical objects and constraints to eliminate many “dead points” in program space, such as programs with syntax errors (Begel 1996). Although these are very positive steps, they continue to reinforce the separation between the physical manipulation of LEGO and the computational construction of Logo.

### **2.2.2 Encapsulating Function and Symbolism**

Chapter three will explore the powerful ideas kids can explore when they build an object with integrated symbolic and functional properties. This section introduces the genuine object encapsulation of functionality in a symbolic container from a user’s perspective: it discusses how such an encapsulation can make this functionality more usable.

For the sake of diversity, let me introduce as an example a non-Doctor genuine object that several of us designed for the Tenth Anniversary of the Media Lab (Borovoy, et al. 1996). We

wanted to create interactive name tags for the guests, which they could program with their answers to the same five multiple choice opinion questions. When they met up with another guest as they wandered around, the name tags would flash depending on how much the two people had in common. We had worked out suitable technology to get the “Thinking Tags” to interact with each other, but were having a hard time figuring out a user-friendly way for people to program their opinions into the Tags. Ultimately, we created a “programming via dunking” approach, where guests could dunk their tags into paint buckets that corresponded to their answers. There were five different “bucket kiosks”, one for each question, and each kiosk had three buckets, corresponding to each answer. The programming-via-dunking approach turned out to be very accessible form of light-weight programming. We demonstrated the process to a few early arrivals, but after that, guests seemed to teach themselves and teach each other how to use the buckets.

Dunking in a paint bucket worked well for badge programming partly because it is an appropriate metaphor for it. Lakoff and Johnson carefully detail the different dimensions of objects that define how we conceptualize them, and therefore define their appropriateness in helping us to metaphorically understand something else: perceptual, motor, functional, and purposive (1980). The programming buckets adhere to three of these, as described in the next paragraphs. If they adhered to all of them, they would cease to be metaphors, and instead would be actual paint buckets.

**Perceptual:** The programming buckets looked like paint buckets, because they were actually paint buckets purchased from Home Depot.

**Motor:** Guests interacted with the programming buckets to a large extent like they would interact with a regular paint bucket: they dunked something in it, left it in for a second, and then pulled it out. This is what one does with a brush in a paint bucket.

**Functional:** Lakoff and Johnson define this dimension as being very literal, so here the paint bucket and the programming bucket diverge. No paint is actually transferred from the bucket to the tag.

**Purposive:** Programming buckets fulfill most of the purpose of paint buckets. Namely, they transfer a substance (bits in one case, paint in the other) from the bucket to the object inserted into it. The paint/bits parallel was emphasized by associating each answer and its corresponding bucket with a particular paint color. Even the purpose of the brush, as a carrier of this substance from the buckets to some other ultimate target, is preserved in the purpose of the Thinking Tags: they also carry their paint/bits to the target destination of another person, where they get transferred (but not permanently) to his or her Tag.

Use of metaphor in Graphical User Interfaces is nothing new, but a genuine object metaphor can be much richer than a GUI metaphor. Although an on screen metaphor like a trash can can have the same purpose as the real thing, the way it looks and the way a user interacts with it physically is purely iconic: the image of the trash is an icon for an actual trash can, and the way a user drags the document to it is an iconic reference to an actual “throw it away” motion. Contrast this with the genuine object programming bucket, which from a perceptual and motor perspective is *actually* a paint bucket. By preserving the perceptual, motor, and purposive aspects of an object while simultaneously swapping out the functional aspect, GOOP allows a familiar interaction with a physical object to become a compelling interface to a new functionality. The more this functionality matches the purpose of the object, the more natural and compelling the interface is.

The programming buckets demonstrate the dual functional/symbolic nature of a genuine object. The genuine object symbol suggests to the user an appropriate metaphor through which to view the object. The metaphor tells the user how to interact with an object, what to expect from this interaction, and subsequently how to interpret it. It is the key to making the functionality accessible.

The functional and symbolic aspects of a genuine object are both dependent on and independent of each other. The functionality must generate behavior that fits with the users’ interactions and expectations generated by the symbol, but the mechanisms by which it does this are completely

unspecified. As long as users' expectations are met, they will remain completely unaware of the mechanism, and instead attribute causal power to the metaphor. Variants of this phenomena are discussed by Lakoff and Johnson (1980), and by Roland Barthes in writings on naturalization (1957). Because of this phenomena, genuine objects can make the powerful behaviors of complex mechanisms accessible to people without their having to be aware of the mechanisms.

Here is a careful explication of how the above process works with the programming buckets: The symbolism of the programming buckets suggested to guests a paint bucket metaphor, which told them that by dunking their tags in the bucket and pulling them out, there would be some transfer of info-paint. In fact, the dunking metaphor was just a way to get them to put their tags in close proximity to an infrared (IR) programmer hidden in the bucket. The buckets played no real functional role (other than a little IR shielding that could have been done other ways). Once users established the tag/IR-programmer proximity, the tag received some IR blasts from the IR-programmer, satisfying users expectations that some info-paint had been transferred to their tag. By conceptualizing the device as buckets filled with info-paint, however, users could successfully interact with and make sense of the materials, without having to consider the complex underlying mechanisms.

### **2.2.3 How GOOP Encourages The Integration of Function and Symbolism**

In the case of the Nine Techno Girls' City, after they decided they wanted the user to be able to determine which language the Professor would speak in, they spent a considerable amount of time trying to come up with a way to encapsulate this functionality metaphorically. As mentioned above, they iterated through a few different ideas for the language-determining genuine objects, including using mouths and hats. I wondered whether they were considering the suitability of these objects simply with respect to themselves, but when I asked them how they were choosing between designs, they said very clearly that they were thinking about which one would communicate the bilingual idea. They seemed to have grasped very quickly that they needed to build objects with a dual purpose: the object must effect a desired behavior, and communicate to the user the nature of this behavior and how to access it. The first purpose is common to many

construction environments, but the second is more unique to GOOP. The following key aspects of GOOP technology encourage kids to think about this second kind of social functionality.

**Orthogonality of Form and Function:** When constructing genuine objects, the creation of the object's behavior can be considered independently of the creation of the object's symbolism, making it much easier to consider both these dimensions. With earlier real-world behavior construction environments, a builder's ability to focus on the communicative/symbolic nature of his or her creation was limited, because the mechanisms required to create the desired behavior determined much of the form.

When building most genuine objects, however, the behavioral requirements put very few constraints on the construction. This is because much of the behavior of the genuine object is determined by its software, and by its effect on other genuine objects. Of course, some genuine objects, like the Doctor's car, have their forms determined more by their mechanisms. However, other genuine objects that communicate with objects like the car have no physical mechanism of their own besides their small "identity block." Therefore, a large amount of "form bandwidth" is left over and can be used purely for the purpose of communication. For example, the Doctor has a pair of "light finding glasses" that, when attached over his eyes, process their raw data to tell him which direction a light is coming from. The builder of this genuine object was free to make it almost any form he wanted; the functional requirements of the glasses determined only one small block out of the roughly one hundred that he used. A student who chose not to utilize this expressive bandwidth would become very aware of the omission, because all of his or her genuine objects, regardless of functionality, would be single LEGO blocks. He or she would probably feel some pressure to "decorate" these blocks in a manner appropriate to their functioning.

**Learning by Example:** GOOP encourages kids to consider the dual nature of genuine objects by making it salient in pre-built examples. Before students attempt to build new genuine objects, they will have experimented with other pre-built ones. In the case of the Nine Techno Girls, before they built the flags, they had already played with the mouth and eye genuine objects of the Doctor. Therefore, it is not surprising that the first idea they came up with for controlling

which language the Professor would speak was to have two different mouths. One gets the GOOP idea very quickly from a few examples; I would have been very surprised if after playing with the Doctor, the girls suggested that they could just put a switch on the Professor to control what language she speaks.

**Audience Feedback:** Initially, students might not build genuine objects that effectively communicate their utility to an audience. However, these students will get feedback on their success when others interact with their creations. After they see whether their creations work both functionally and metaphorically, they can make appropriate modifications. Maria and Adrianna got some feedback on this after they built their language flags. They had built an American flag to signify English, and a Puerto Rican flag to signify Spanish. Although the flags behaved appropriately when Maria and Adrianna showed them to the group, several of the other girls thought the Puerto Rican flag did not evoke “Spanish” as much as a Mexican flag would. Therefore, Maria and Adrianna built a new Mexican flag.

**Reciprocal Leverage:** Adrianna and Maria seemed to give about equal weight to constructing the symbolic and functional aspects of the flags. The two dimensions leverage each other: an effective symbol can cue a metaphor that makes a particular behavior much more meaningful, and behavior breathes life into an otherwise hollow symbolic shell. With original, static LEGO, kids had to animate their creations by moving things around with their hands. Because this behavior never became fixed or “objectified”, however, there was no way to stand back from it to see whether the behavior could be effectively interpreted in terms of the metaphor suggested by the LEGO’s symbolic form. While traditional LEGO is rich with symbolism but weak on behavior, LEGO/Logo offers rich behaviors, but less “expressive bandwidth” available for symbolism. With GOOP, the two modalities are balanced: symbolism motivates functionality, and functionality motivates symbolism.

## 2.3 Genuine Object Interaction

GOOP provides a software and hardware architecture that enables all genuine objects to interact with each other in a seamless fashion. From the user’s perspective, an object can communicate

with any other object, no matter where they are located; it does not matter if they are plugged in to the same character, or if they are using IR to communicate wirelessly. The user specifies this communication in exactly the same way, regardless of which communication medium is involved. For example, if the user wants to program the Doctor to react to something only if the Doctor is smiling, the user can write `“if doctor’s mouth expression = smile [...]”`. If the user wants the Doctor to react to something only if the *Professor* is smiling, the user writes in the Doctor’s code `“if professor’s mouth expression = smile [...]”`. The latter of these results in IR exchange between the Professor and the Doctor; the former executes locally to the Doctor. The user does not have to worry about the difference, however. In addition to passing information, objects can also control each other using a very similar syntax. For example, the Doctor can make the Professor smile by executing the code `“setProfessor’s mouth expression frown”`.

Not all messages between objects are generated by the user. GOOP provides a built-in “event loop” which continuously scans all its object sensors to see if an object has been added or removed. When an event is detected, a message is automatically sent to the relevant object. Therefore, in order to build an object that performs some function when it is added to the construction, all the student needs to do is associate a piece of GOOPLogo code with an object’s “I’ve been added” message. In this code, the student can easily check other information about the object, such as where it was added, and information about other objects that might help determine the new object’s behavior.

GOOP’s object sensing, object interaction, and event loop architecture provide a layer of abstraction above the laws of Newtonian mechanics that govern how physical objects interact. In behavior construction kits like LEGO/Logo, if users wanted objects to interact, they had to deal directly with these rules. For example, if they wanted to make a car go, they had to run a wire to a motor to supply electricity, and then attach a series of gears to the motor to reduce the mechanical power, etc. The messiness and non-linearities of mechanics made these activities inaccessible to some people.

With GOOP, we have encapsulated much of the complexity of Newtonian mechanics inside the genuine objects, and defined a new kind of mechanics — a new set of laws for how genuine objects interact — on top of them. With these technologies, kids can begin to invent their own laws, defining for themselves what effect Object A has on Object B. Equally important, there are no side-effects, so if the user does not want Object A to affect Object B, no interaction will occur. Of course, interactions between genuine objects are limited, and if a student wants to build a faster car, he or she will still be forced to go a layer deeper and deal with the mechanics of gear trains.

The evolution of the LEGOHead camera demonstrates GOOP's path toward creating a higher level of abstraction for physical object interaction. Originally, the flash of the bulb on top of the camera is what told the Doctor his picture was being taken. Using visible light for this kind of communication was messy, however. People using the camera had to pay very close attention to how much ambient light there was in the room, how close they held the camera to the Doctor, and so on. In short, visible light meant visible Newtonian mechanics. Later, I substituted IR communication for the visible light. I still put a flashing bulb on top of the camera, because this helped evoke the camera metaphor, but it no longer played any functional role. Now, the camera could be programmed by saying "if camera's shutter-button clicked? [announce-over-ir [picture taken]]" This would send a message over IR that a picture had been taken. The Doctor would respond to this if in his program was "if heard-over-ir [picture taken] [say cheese]". Translation: if Doctor hears a message via IR that a picture has been taken, he says "cheese".

The camera example shows how GOOP creates a new, more accessible system of interaction between physical objects, and how it can hide from sight some of the older and messier Newtonian system. In the above example, the Doctor can "see" the camera because of its IR communication. IR also enables genuine objects to appear to talk and listen to each other. For example, the "say" command (e.g. "say [cheese] "), which uses the Doctor's speech synthesizer to speak a string of text, also automatically transmits this text over IR. Using an "if heard [ . . . ]" sequence (e.g. "if heard [cheese]"), the Professor can "listen" for this IR transmission, and then

respond to it as if she were responding to the spoken utterance of the Doctor. Of course, this is limited to utterances between genuine objects; the Professor will not respond to something that a user says. However, their pseudo-vision and pseudo-hearing capabilities do allow genuine objects to be able to “sense” each other in high-level ways.

### 3: An Construction Environment for Children to Explore Theories of Mind

*When you photograph the Professor, you can first place her facial features in a desirable pose. For example, you can turn her mouth into a smile, and have her look at the camera, or make her frown and have her look away. When you are done shooting, you can transform the camera into a slide projector by removing the light from its “flash bulb” position and placing it inside the lens. Now, when you point the projector toward the Professor and click on its button, you can replay the slides you took: with every click, the Professor recreates the pose you put her in for that slide.*

*If you photograph the Professor with the camera while the Doctor looks on, he will comment on what he sees. Of course, what he says depends on what moods the Professor and he are in. If they are both smiling, the Doctor will say nice things about the picture you’re taking of the Professor, like “I want a copy of that one”. If a smiling Doctor sees you photographing an unhappy Professor, he will try to humor her in to a grin. Sometimes this works, and the Professor will smile. Other times, she just roles her eyes. If the Doctor is unhappy, and you are photographing the Professor instead of him, he gets jealous. He’ll tell you that she may be a good picture, but he’s a better demo.*

Consider the “community of knowers” that exists in the above Doctor and Professor Photoshoot scenario. There is the Professor, who knows that her picture is being taken. I use “know” here to mean she is capable of discerning and reacting to the event of the LEGO camera being pointed toward her face, and the shutter button being clicked. She also can differentiate between the camera and the projector. There is the Doctor, who demonstrates a more sophisticated awareness of the camera’s gaze and the Professor’s location by differentiating between the Professor and himself being photographed. The Doctor also exhibits awareness of his own facial expressions, and those of the Professor. There is a knowing “audience”, possibly the camera operator, who participates in the unfolding scenario, making inferences about what the two creatures know based on their behaviors and his or her own knowledge. Finally, there is the engineer of this whole fantasy, who knows what the Doctor and Professor know because he or she programmed them, and who had to know something about the audience in order to make the scenario evocative.

One of constructionism’s goals is to offer children environments where they can reflect on their own process of understanding by reifying it in the tangible form of computational media. Current research in people’s Theories of Mind suggest that what we know about what other people know,

and how we make sense of how they make sense are crucial to our own understanding of the world. Any environment designed to allow children to reflect on this more social view of cognition must therefore allow them to reify their understandings not simply in the form of a tangible mental model, but more in the form of a model community. GOOP allows a student to experiment and play with a model community of knowers — a community of Things That Think in which he or she is “not just the president, but also a member”. This means that the student is not the only one who knows: other computational entities in the community know things about themselves, know things about each other, and even can know something about the student.

Other computational construction kits have emphasized building communities, but none have shared GOOP’s focus on communities of knowers. Amy Bruckman has built an environment called Moose Crossing, where kids can create an text-based on-line community of people, places, and things (Bruckman 1994). There are some similarities between the kinds of scenarios a child can construct with Moose Crossing and with GOOP. The purely digital and text nature of Moose Crossing constructions enables a child to build more elaborate things. Also, Moose Crossing offers a real community of people to interact with. However, for reasons discussed below in the section on intersubjectivity, the on-screen and text nature of Moose Crossing constructions potentially limit a child’s ability to conceive of the other characters’ subjective minds, and therefore to link his or her own subjectivity to theirs. If children are going to explore these powerful ideas, they need to do it in an environment that makes the ideas’ underpinnings as concrete and familiar as possible.

Mitchel Resnick’s StarLogo environment allows children to create an on-screen community of thousands of interacting creatures in order to explore powerful ideas about distributed systems and emergence (Resnick 1994). Much of this work is concerned with how intelligent global behavior, or a “hive mind” (Kelly 1995), can emerge from the interactions of a large set of similar mindless components; therefore, the individual minds of the creatures are de-emphasized in StarLogo. The environment is not geared toward giving the user a strong sense of a particular creature’s subjectivity, or linking subjectivities between creatures and users.

The following two sections focus on the powerful Theory of Mind ideas students can construct when playing with and in a model community of knowers. The first section focuses on how “things”, such as the Doctor’s camera, are constructed in such a community, both physically and cognitively. In this section, the community I am referring to consists mainly of the creator of a genuine object and the user of that object. The Doctor is there, but only as a peripheral participant. The second section explores what powerful ideas kids encounter when they start to actively engage with objects that possess primitive “minds”, such as the Doctor. The chapter concludes with a summary and final analysis of how GOOP helps students examine and expand their own Theories of Mind.

### **3.1 Building Things, Building Concepts, Building Myths**

When a student builds a genuine object, such as the camera in the above scenario, he or she is not just building a piece of functionality; the student is also creating a metaphor to make this functionality understandable to an audience. By metaphor, I mean the conceptualization of an unknown functionality in terms of an object known to the audience. In the case of the camera, the functionality that the user must build relates to capturing and saving the state of a particular Thinking Thing. However, such functionality could be encapsulated in a variety of objects, such as a digital logbook or a wand. The student must devise a metaphor that gives a user a concept of what functionality the object offers, and how to make use of that functionality. In other words, the student must explicitly and tangibly build both a function, and a conceptualization of that function. This dual functional/conceptual nature of genuine objects makes them powerful objects to think with.

#### **3.1.1 The Non-Essential Nature of Things**

One of the first ideas that a student encounters when constructing a genuine object is that an audience’s conceptualization of an object does not simply flow from the object itself. Instead, the audience’s understanding depends on what prior understandings they bring to bear in their interpretation of their present experience of the object. Lakoff and Johnson talk about these prior

understandings as metaphors (1980); Schank calls them scripts (1977); Minsky calls them frames (1985). Whatever they are called, they play an enormous role in how we experience the world, although we are seldom aware of their influence. Instead, our minds create the illusion that our current experience arises directly from “essential” properties of the objects around us.

Frames set expectations about how the world around us will behave (Minsky 1985), but people remain unaware of these expectations as long as they are met. This is why it is frustrating to be a good product designer: if the product you design effectively delivers on the expectations it sets, then users can ignore the design altogether. It is only when something is broken, in other words it fails to meet users expectation, that they become aware of them.

All the genuine objects I have discussed so far — the camera, the buckets, the Doctor’s mouth and ear — were designed to meet the expectations they raised. However, the key aspect of GOOP technology is that it makes distinct the part of the object that raises these expectations from the part of the object that delivers on them. This deconstruction means that students can swap two LEGO bricks on the Doctor’s mouth and ear, and suddenly the Doctor will talk when they attach his ear, and listen when they attach his mouth. In this slightly jarring experiment, the students’ violated expectations are thrust into view. In their attempt to discern the “nature” of this half-ear/half-mouth object, they can confront the importance of both observed function and prior understanding in their conception.

### **3.1.2 Choosing an Appropriate Metaphor**

Even when students attempt to design genuine objects that meet the expectations they set, they will find there is not one right way to do it. The two members of the Nine Techno Girls explored several different possible metaphoric encapsulations of the bilingual functionality they constructed. In this way, the genuine object becomes a model of the non-deterministic relationship between conceptualized and concept. Students can encounter the idea that there are multiple ways a phenomena can be understood, and that different ways are better for different contexts. This resonates with Turkle’s and Papert’s ideas of “Epistemological Pluralism” (1992).

The process of choosing an appropriate metaphor for the behavior of a genuine object gives students access to some of the most powerful ideas associated with GOOP. Described below are two evaluative metrics students can “try on” in choosing an appropriate metaphor: familiarity and naturalization. I do not claim that students will uncover these metrics on their own using GOOP. Combined with the appropriate coaching and culture, however, GOOP materials can offer a supportive environment for exploring these issues.

**Familiarity:** Students can not build from scratch a whole concept for their audience to understand their genuine object. Instead, they can only cue a pre-existing frame, or metaphor, in the mind of the audience. Therefore, students must carefully consider what frames their audience carries around with them. This sounds trivial, but I would argue that we are never sufficiently sensitized to the pre-existing knowledge that an audience brings or does not bring to any kind of presentation or communication. Once students building genuine objects accept their communicative function, as Maria and Adrianna seemed to have done quickly, they must deal with whether a particular metaphor will communicate with a particular audience.

**Naturalization:** Once students have decided that a metaphor is familiar, they have to consider how well it fits the behavior of the genuine object. I use Barthes’ concept of naturalization (1957) to suggest that the right metaphor should make the way the user interacts with the object, and the way the object behaves as a result, feel completely natural. The metaphor and the mechanism should fit together in such a way that for the audience, the mechanism disappears, and the metaphor takes over: the flags work because they specify the nationality of the Professor, the buckets work by coating one’s badge with info-paint. In other words, metaphor and mechanism come together in a genuine object to form what Barthes defines as a myth, a communicating object whose mechanistic origins are naturalized away.

The secret to naturalization is to find a metaphor whose affordances match those of the technology. It is common to think about technology as having affordances. Lakoff and Johnson suggest that metaphors also have affordances, in terms of concepts they make salient, and ones they hide (1980). A naturalizing metaphor will highlight ways of interacting with the technology

that are possible, and make it hard to conceive of ones that are not. It will also set appropriate expectations about the outcome of those interactions.

GOOP's use of IR technology provides an example of affordance matching. The fact that IR communication is "line of sight" is often considered a limitation. However, when this mechanism is encapsulated in the metaphor of human-like gaze, the line of sight quality of IR becomes completely natural and expected. An audience would be surprised and disappointed if the Doctor could see something behind him. This could easily have been the case, however, if the Doctor used radio communication, instead of IR. ELIZA, the famous software that imitated a therapist, was a classic example of affordance matching: its creator chose the metaphor of a Rogerian therapist ("It sounds like you're saying that ...") to naturalize the computer's modest ability to repeat back things the user said. For an example of poor metaphor/mechanism affordance matching, consider the Apple Newton, which could not possibly deliver on the expectations generated by its notebook metaphor.

Students will acquire a powerful skill if they learn to create a myth of functioning by finding a metaphor to naturalize the behavior of an idiosyncratic mechanism. More importantly, experience producing naturalizing metaphors will probably make students more savvy consumers of them; by learning how to construct these technology myths, students should also learn how to deconstruct them. I believe this is a crucial part of "Technological Fluency" (Papert and Resnick 1995). The ELIZA program would not have fooled as many people if they had experience constructing such illusions themselves.

### **3.1.3 Cueing**

After students have chosen appropriate metaphors for their genuine objects, they must figure out how to "cue" them in the minds of the audience (Minsky 1985). For example, once I had decided on the right metaphor for the "save this state" functionality, I still had to determine the most salient aspects of "cameranness", so I would include these key features in genuine object design. This kind of thinking is similar to what one does when playing "Pictionary", and one is trying to evoke a particular concept to an audience with the least amount of drawing possible. I

discovered that a flash bulb and a protruding lens were the keys to evoking “camera” in most audiences.

Since humans do not normally notice their use of frames in comprehending experience, they certainly do not notice how these frames are cued by specific features in their environment. GOOP gives students experience in the process of constructing effective cues to evoke a particular frame. An understanding of this process can allow students to influence the frames others will use in interpreting their work. It can also lead to “Cue Literacy”, where students become more aware of how cues are used to influence their own understandings.

### **3.1.4 Different Levels of Understanding in a Community of Knowers**

In addition to exploring the multiplicity of ways a phenomena can be conceptualized, GOOP can help children explore the distinctions between multiple levels of understanding across a community of knowers. For example, as creators of the flag genuine objects, the girls had a different level understanding of how they work than someone who just used them. To a user, they work because the flag determines the Professor’s nationality, and consequently what language she speaks. To the girls, the flags work because they have defined an “when attached” method for each flag which sets a variable corresponding to which language should be spoken by the mouth. To me, the creator of GOOP, the flags work in a still more complex fashion.

Different levels of understandings by people who have different “needs to know” are perfectly normal and common. What is new is the way GOOP students construct at these multiple levels simultaneously. By encouraging students to consider the high-level understanding of their audience while they are expanding their own lower-level knowledge, they can discover that one level is not more correct than another. Instead, they can see that how much one needs to know is determined by what one needs to do.

## **3.2. Building Minds, Building Intersubjectivity**

The first sub-section below describes how the Doctor gives off the illusion of a shared understanding: how when he reacts to the disco set, the audience perceives him as inhabiting the

same physical and cognitive landscape as themselves. If GOOP only put students in the role of audience for these illusions, however, it would not be very powerful. Instead, GOOP lets students play the role of illusionist, creating from scratch the illusion of intersubjectivity between the Doctor and the audience, thereby exploring the nature of distributed knowledge. The following sections document the process of building the intersubjectivity illusion in GOOP, and the powerful ideas that it makes tangible.

### **3.2.1 The Illusion of Intersubjectivity in GOOP**

When I hold up the disco set for the Doctor to see, he reacts to it only when I would react to it if I were him — in other words, only when it is within his line of sight. Technically, this works because the IR transmitter is located in the disco set, the receiver is positioned inside the Doctor's eyes, and the result roughly simulates the “line of sight” properties of human vision (see Figure 3.2). Cognitively, this results in my attributing to the Doctor a system of perception similar to my own: namely, a focused gaze, and a resulting subjectivity. I believe there are things the Doctor can see, and things he can not see; things he is aware of, and things he is not. When the Doctor and I can both see an object, and he reacts to it in a way that I recognize as appropriate — in a way that I myself might react to it — then I make the more powerful attribution that the Doctor and I have intersubjectivity (see Figure 3.4) (Benjamin 1990, Goncu 1993). I feel that we are physically and, to some extent, cognitively living in the same world.

The disco set is designed to be a miniature Seventies disco scene that one might have seen on television. It has a “Geometric Art” background, a multi-colored floor, and a big shiny disco ball with a “strobe light”. When someone sees the disco set genuine object, he or she is meant to be transported back to the era of Saturday Night Fever (obviously, I had adults in mind when I constructed this object). When the Doctor sees the disco set, he appears to be transported back to this era as well: he immediately exclaims “I must dance!”, and then waits for the user to start flashing the strobe light. When this happens, the Doctor starts doing a dance resembling the Hustle, and periodically calls out disco lyrics such as “It's fun to stay at the YMCA”. The Doctor acts in a way that suggests he is nostalgic for, and therefore knowing of, this bygone era. He does

### Figure 3: The Illusion of Intersubjectivity

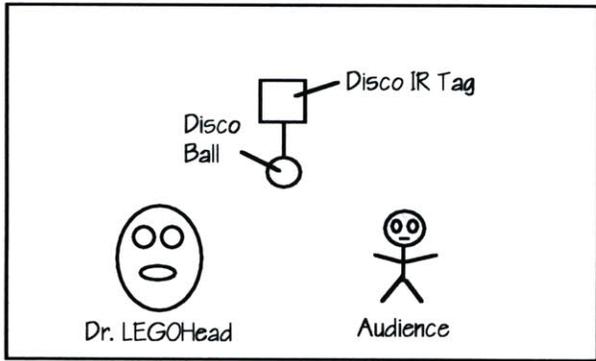


Figure 3.1

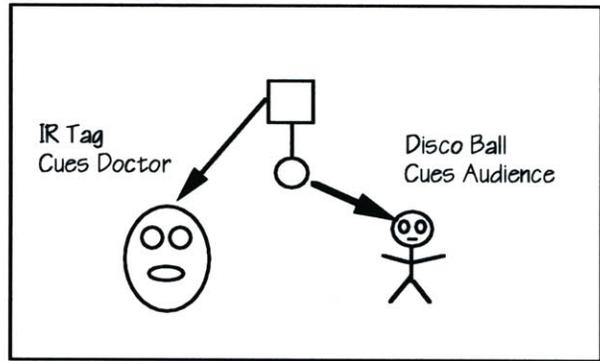


Figure 3.2

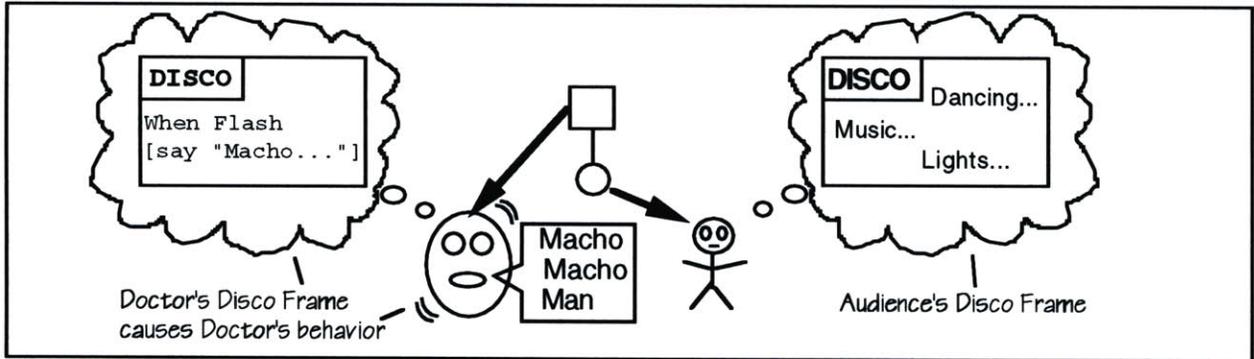


Figure 3.3

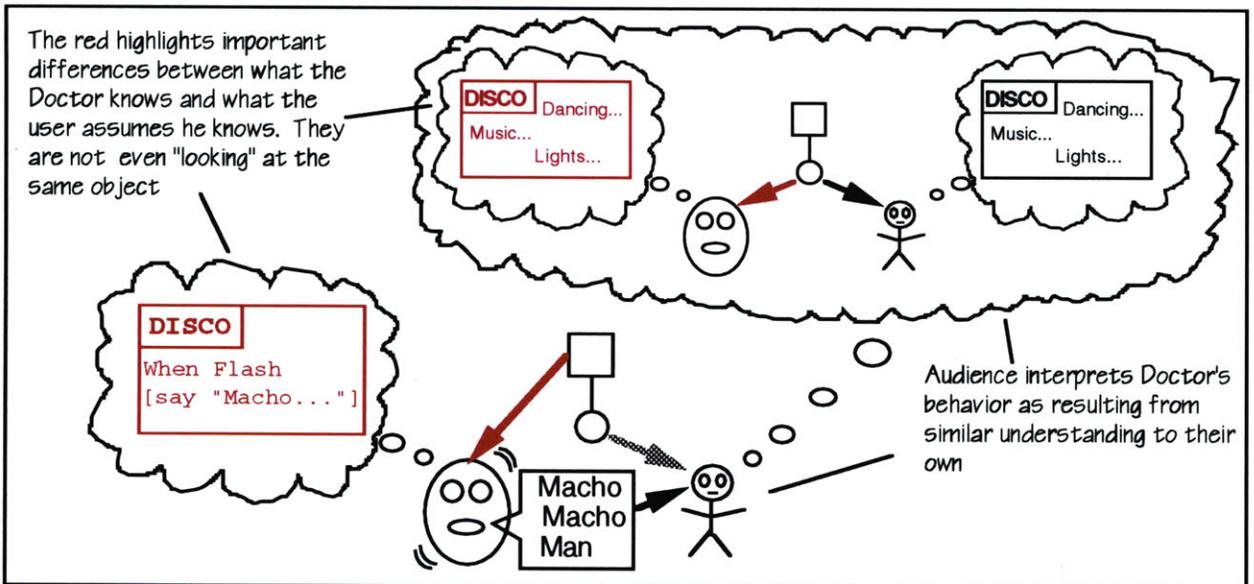


Figure 3.4

not wait for the user to accept him as a fellow “knower”, however. Instead, the Doctor’s seeming confidence that his display of hipness will be understood turns the tables; it suggests it is he who is willing to accept his audience into this knowing club. If users are flattered by this, they have already accepted the intersubjectivity between themselves and the Doctor.

Of course, the intersubjectivity between the Doctor and the user are mostly illusory: they are not really seeing the same thing. To the user, the disco set is an evocative shape made out of LEGO. To the Doctor, the disco ball is an IR beacon broadcasting a specific digital code. The elaborate disco set is as irrelevant to the Doctor as the IR signal is to the user. The illusion works only because these two different entities can be collocated in roughly one point in space without interfering with each other, and because the Doctor can be programmed to respond “as if” he sees what the user sees. Although this intersubjectivity is illusory, however, it is still very engaging.

Contrast the Doctor’s ability to “sense” the disco set with a LEGO/Logo creature’s ability to sense the amount of light falling on one of its sensors. The ability to recognize an object feels much more human than the ability to sense how much light there is. Students are less likely to feel a shared understanding with a creature whose sensing ability is so seemingly limited, and foreign from their own.

How would the Doctor be different if he were a character on a computer screen, as opposed to a Thinking Thing? This is a question that comes up frequently, and one of the main answers relates to intersubjectivity: Users would be less inclined to believe an on-screen version of the Doctor and they have a shared understanding of the world. There are several factors that contribute to this. First, characters on a computer screen rarely have well-defined gazes and therefore rarely have well-defined subjectivities. What would it mean for the on-screen Doctor to be able to be aware or unaware of an on-screen version of the disco set? Users might be inclined to assume that the character is omniscient, knowing everything that is going on in the computer. The well-known concept of a computer agent that is able to observe all our on-line work supports this belief.

Even if an on-screen character had a discernible subjectivity, why would users believe that their subjectivities align with the character’s in any way? They are hindered in their ability to come to

know about the objects on the screen, since they cannot touch them, and it would be hard for them to fathom how the on-screen Doctor perceives these objects. Their subjectivities seem separated from the character's by a plate of glass. The screen as divider of two worlds is the subject of a lot of movie and television mythology, where characters periodically step from behind the screen into the "real" world, or somehow get sucked from reality into TV land. Recently, technology has attempted to bridge the subjectivity gap presented by the screen, in the form of avatars. An avatar is a representation of a user that can enter the on-screen world under his or her control. This character, which is on more equal footing with other on-line characters, is a possible bridge between other characters' subjectivities and the user's. Perhaps with such an avatar, a user could feel a shared understanding with an on-screen Doctor. It is hard to imagine it would have the same intensity as with a creature that so clearly shares one's physical space, however.

### **3.2.2 Constructing Shared Understandings**

One can see from Figure 3 the complexity of a shared understanding (or, in this case, the illusion of a shared understanding). Shared understandings are hard to draw; they are even harder to talk about. One winds up very quickly saying incomprehensible things about "what he knows about what she knows about what he knows..." There is a clear role for constructionist environments to make such understandings more tangible and accessible to children by manifesting them in physical objects.

Students can learn a lot from constructing the Doctor's understanding of an object. The first thing they may be surprised to learn, however, is that such a construction process is necessary. When students play with the Doctor, they quickly come to take for granted the knowledge embedded in his many genuine objects. Indeed, the fact that they can take this knowledge for granted is what makes genuine objects powerful. After a while, they may give way to the illusion of intersubjectivity, and believe that the Doctor will recognize a new object it has never seen before just because they recognize that object. Of course, this illusion is shattered quickly when they test it, exposing a fundamental truth: the Doctor's world awareness, which seems so natural, is actually carefully constructed for him, piece by piece.

When it is first constructed out of LEGO, an object like the disco set, although plainly visible to its builder, is completely invisible to the Doctor. Right away, a student can see that he or she has a very different subjectivity than the Doctor, and that they do not naturally live in the same world. The first thing a student must do to bridge their worlds is to imbed a special IR identification tag in the object, so that the Doctor can “see” it when it is placed in front of him, and respond with some default behavior, such as a beep. As mentioned previously, the fact that the Doctor’s vision seems to be governed by the same laws (e.g., line-of-sight constraints) as the student’s makes the student feel like they have the beginnings of a shared reality. In order to expand this shared reality, the student must help the Doctor demonstrate he understands the meaning of what he sees. For example, in the case of the disco set, the student must program the Doctor to react appropriately when he first enters the disco, and to when the disco light flashes.

I believe a student’s ability to control the subjectivity of the Doctor, incrementally aligning it with his or her own, is a unique and powerful experience. At the beginning, the invisibility of the disco set to the Doctor makes the subjectivity gap very salient. By the time the Doctor sings “Macho, Macho Man” when he sees the strobe light, it is this gap that has become invisible: the Doctor’s behavior lines up with the audience’s expectations, and all the programming and IR communication disappears into a scene that simply feels “real”. In some ways, this is the same intersubjective reality that research shows we first construct at a very young age (Wellman 1990), and that we take for granted from then on. GOOP challenges the taken-for-granted nature of shared understandings by allowing students to construct and deconstruct them for themselves.

### **3.2.3 Constructing Frames**

In Section 3.1.2, I discussed the large role that prior knowledge, in the form of frames, played in an audience’s understanding of a genuine object. Students get to experience these frames by attempting to cue appropriate ones in the minds of the audience. GOOP also offers students a much more tangible way to explore these frames, however; students can build them directly into the “mind” of the Doctor. For example, the person who built the disco set also built a disco frame for the Doctor that told him how to behave in a disco. This frame contained knowledge such as

“when entering disco, say something cool” and “when strobe light flashes, dance”. Obviously, this is a very primitive, “behaviorist” frame, but it provides for a little of the interpretation and behavior mechanisms that a more powerful human frame would.

The student must explicitly construct a frame in the mind of the Doctor in order for the Doctor to successfully interact with a genuine object. The student must also make sure the appearance of that genuine object cues an appropriate frame in the mind of the audience. All this attention to the frames of the Doctor and audience should heighten the student’s awareness of just how much “disco-ness” resides not in the disco set, but in the minds of the community of knowers. This is a very potent direct experience of the role socially distributed knowledge plays in our construction of reality. Because reality normally appears to us as a given, this window provides a rare glimpse into its mechanisms. By giving students the chance to build these kinds of realities, GOOP gives students previously inaccessible insights into their workings.

### **3.2.4 Constructing Communication**

One of the major benefits of human’s elaborate shared understandings is our ability to communicate efficiently: We can “compress” a message in terms of this mass of shared knowledge, confident that the recipient will have access to the same set of knowledge to decompress it. GOOP allows students to explore this phenomena by enabling message passing between GOOP objects that leverage their shared understanding. For example, because the concept of a mouth is part of the common knowledge base of the Doctor and the Professor, the Professor can inquire about the Doctor’s mouth expression at a high level, knowing that Doctor will make appropriate sense of the request in terms the low level details of his mouth.

By building communicating genuine objects, kids can explore different points along the inverse relationship between message complexity and depth of shared understanding. Nicholas Negroponte talks about this relationship in terms of “debunking bandwidth” (1995). He uses the compelling example of a wink which, because of a rich shared understanding between participants, can communicate volumes, even though its complexity is low. His argument that bandwidth is misunderstood, and consequently over-valued, points to how poorly these basic issues of

communication are understood, and why we should build environments for children to explore them.

### **3.2.5 Constructing Theories of Mind**

What do the following things have in common: Understanding how to cue a frame that the audience possesses to help them understand the functionality of a genuine object; becoming aware of the role knowledge plays in the Doctor's awareness of his world; knowing what knowledge the Professor and the Doctor share so they can communicate with each other at a high level. The answer is that they all involve a person's understanding of other people's understanding. Specifically, they suggest that we cannot understand another knowing entity without knowing something about what and how it knows; we need a Theory of Mind.

A Theory of Mind is not just a binary entity that one either has or does not have, however; it is reasonable to believe that different people have differently evolved Theories of Mind that give them different abilities. For example, some people seem to display a keener ability to maintain their own mental models of other people's mental models. This makes them good at explaining things, because they can run a simulation of a particular explanation in their head, to see how it might be understood by the other person. Consequently, they can iterate through several explanations before actually attempting one, avoiding a lot of possible confusion. These same people are good at diagnosing misunderstandings: they can spot an utterance of someone that does not fit with their model of that person's understanding, and then they can mentally iterate through small variations of this model in an attempt to find one that makes sense of the utterance. Finally, these people can also be good presenters, since they can use their models of the audiences' models to hear what they saying the way the audience hears it, and adjust their presentation if they stray too far toward the known or the unknown.

GOOP encourages students to develop their Theories of Mind in a way similar to how LEGO/Logo encourages students to build theories of gears. In order to successfully build in GOOP, a student must constantly consider things like what the world looks like from the Doctor's perspective, and what knowledge frames the audience possesses. Students have unprecedented

ability to directly examine and manipulate the contents of some of the minds in the community, such as the Doctor and Professor. However, these same minds can also function as autonomous entities, reacting to stimuli without direct intervention from the students.

GOOP is unique in its ability to let students alternate between controlling a mind and then letting it function on its own. Toys like dolls and puppets allow kids to pretend to create artificial minds, but the fidelity of this simulation is greatly limited by the blurring of boundaries between the child's mind and the doll's. Dolls lack the necessary agency to demonstrate any kind of mindfulness. The Doctor comes much closer to actually having "a mind of his own". On the flip side, children have lots of access to communities of autonomous minds, in the form of their family and friends. However, their inability to fully examine, manipulate, and construct these minds leads to an incomplete understanding of them. GOOP gives kids the materials to construct Theories of Mind the same way that the LOGO turtle gives them materials to construct their own theories of geometry.

## **4: Why GOOP is Accessible and Engaging**

Chapter 3 discussed the powerful ideas students can explore by constructing their own genuine objects. Of course, it does not matter how powerful these ideas are if students do not want to or can not build these objects for themselves. Therefore, GOOP provides a smooth and engaging path from novices' first contact with pre-built genuine objects all the way through their ultimate construction of genuine objects of their own. Fortunately, the same properties that make GOOP cognitively rich also make it accessible and engaging: the same myth of functioning that experienced students learn so much from constructing can draw in novice builders, and initially protect them from low-level implementation details.

### **4.1 Accessibility**

#### **4.1.1 Genuine Object Encapsulation and Accessibility**

Classic research shows that experts employ higher level cognitive structures than novices when reasoning in a particular domain (Newell 1972). For example, in chess, while a novice considers the board in a piece-by-piece fashion, an expert mentally “chunks” the board into larger multi-piece entities. Genuine objects perform a similar function: by encapsulating low-level domain knowledge in higher-level objects, they function as real world proxies for expert chunks.

When novice students start interacting with pre-built genuine objects, they can get away with having only top level understanding of the objects; most of the low-level knowledge can reside in the objects themselves. Since this knowledge is well-structured and accessible, however, students can begin to uncover it and modify it as they become progressively more comfortable with these objects. They can start to construct more of this understanding for themselves, and rely less on what has already been constructed for them. In this way, the pre-built genuine object acts as a fading scaffold for the knowledge it encapsulates. For example, in order to make use of the GOOP car in a construction, students need only understand the basic commands for making it move. When the students want to extend the capabilities of this car, then they can “get under the hood”

and improve their depth of understanding of the object. Genuine objects let people work at the level of understanding appropriate for the task, and help them move between levels when necessary.

#### **4.1.2 Intersubjectivity and Accessibility**

When playing with a LEGO/Logo vehicle, children will often assume that by simply attaching a touch sensor to the front of the car, it will know to reverse direction when it hits a wall. These children apparently assume that because they know this is what a touch sensor is supposed to do, the touch sensor will know it also. This can be considered another form of an attribution of shared understanding. As previously discussed, students get a chance to reflect on these assumptions of shared understandings by building up genuine objects for themselves. However, students who just want to use pre-built genuine objects should find that the objects do, in fact, have some built-in understanding of how they are to be used. A genuine object touch sensor that has been attached to a car can know to back the car up and turn it around when the sensor gets pressed. This will better meet the expectations of the users, allowing them to start building things more quickly with GOOP.

### **4.2 Engagement**

#### **4.2.1 Genuine Object Encapsulation and Engagement**

Many of the genuine objects that have been constructed with GOOP have a magical quality to them which makes them engaging. The magic wand that the girls built for their city is an obvious example, but other objects like the Doctor's mouth also have a magical feel. They are magical because they obey what Barthes would characterize as the central tenet of the magic trick: they hide their own mechanisms, and in their place offer more evocative myths about their functioning (1956). In the case of the Nine Techno Girls' magic wand, the IR input and output devices are hidden. You, the visitor, feel like the wand, and by extension yourself, are interacting directly with the buildings, entreating them to tell their stories with a gesture of your hand.

The magic wand is engaging because of its suggestion to the visitor that he or she has direct, seemingly unmediated access to the city. Technology does not appear to come between the visitor and the building, or determine the nature of their interaction. The visitor does not have to push a button, or drag a mouse around on a screen for information. GOOP technology, with its ability to suggest new systems for object interaction, offers to the visitor an image of a world free from some of the tyranny of everyday mechanics. This is the myth that the magic wand “trick” puts out, rather than displaying its actual mechanisms: the Professor doesn’t speak about the Swan boat because she receives a particular signal over her IR port from an IR transmitter, she speaks about it solely because you pointed at it, because *you want her to*. Unfortunately, this is counter to the world we are all forced to live in. I believe this is what one of the guests at the opening of the Nine Techno Girls’ City had in mind when he said “This is terrific. Why don’t all cities have a magic wand like this?”

#### **4.2.2 Intersubjectivity and Engagement**

The propensity to think of the Doctor as a peer, a fellow member of a community of knowers, makes him a very engaging object. Doubtless, that is why my colleague David Shaffer originally suggested the name of “Dr. LEGOHead, Ph.D.”, designating this toy as an accomplished member of our own academic community. Indeed, the Doctor did become an important participant in our group. He got his own email address, and received postcards from a colleague traveling in Europe. He became something of a “pop icon”, with people imitating his patterns of speech and movement. Group members enjoyed “playing” that the Doctor was a fully sentient member of the group. I would argue that this play was enabled by his modest ability to demonstrate intersubjectivity. The Doctor became a toy we could laugh with, not just at — a play-mate, not just a play-thing.

#### **4.2.3 Building Narratives and Fantasies**

GOOP engages children because it satisfies their desire to create whole stories, interactive scenarios, and fantasies, not just individual creatures or machines. One of the major benefits of

object oriented technology is “domain orientation”, where “software developers feel like they are interacting with the domain itself rather than with low-level computer abstractions” (Fischer, et al. 1995). The same domain orientation that makes genuine objects suitable for building intersubjectivity makes them useful for building narratives: they operate at a human level of description. There are three aspects of genuine objects that make them suitable for the narrative domain:

**Genuine objects represent familiar nouns — persons, places, and things — which are some of the basic building blocks in story construction.** I have already discussed characters like the Professor and the Doctor, places like the disco, and things like the camera. Recognizable things often carry rich meanings with them that evoke good storytelling. For example, one of the first genuine objects built was the Doctor’s mouth. It could be placed on the Doctor in a smiling or frowning position, and it was used to determine his mood in a very early scenario. This object, and the notion of mood that it represented, turned out to be very evocative, and it affected almost all Doctor scenarios there after.

**Events associated with genuine objects represent familiar verbs, allowing the construction of high-level rules about how user and character actions trigger genuine object behaviors.** For example, through inter-object messaging, it is easy to program the camera to announce that it is taking a picture when the user clicks on its button, and it is easy to program the Doctor and Professor to respond to it. This interaction happens at level well suited to the narrative domain. The program in the camera reads “if my shutter-button clicked? [announce-over-ir [picture taken]]”. The Doctor would react to the Camera being clicked with “if heard-over-ir [picture taken] [say cheese]” Although it is by no means perfect, these pieces of GOOPLogo map much more closely to salient elements of the scenario being enacted than more traditional means of programming. Also, the picture taking code is a good example of how students can build a set of rules in GOOP that can then fire in different chains, depending on the user’s actions.

**GOOP allows the construction of rich scenarios involving multiple characters, things and places.** Many interesting stories involve multiple interacting characters and objects. The picture-taking scenario above shows how a chain of firing rules can move across object boundaries, involving a whole community of interacting characters and things. Additional GOOP support for “communities of things” is provided by characters that can easily “see” (via IR) the current states of their peers. It is as easy to inquire into the state of a peer as it is to find out about one’s own state. Users can create rules to act on particular states in the same manner described above.

## 5: Conclusion

### 5.1 Summary of Research Findings

By allowing students to physically engage with powerful cognitive constructs like cues, frames, and metaphors, GOOP allows them to construct for themselves some of the key elements of “mind.” By facilitating their shaping of these elements into genuine objects that appear to an audience to have mythical functions, and into characters that appear to have shared understandings, GOOP pushes students to expand and reflect on their sense of how people make sense — their own Theory of Mind.

Furthermore, the properties of GOOP that allow students to explore Theory of Mind ideas also make this exploration accessible and engaging. A genuine object can initially hide its mechanistic complexity from a novice user, and offer in its place an engaging metaphor to help conceptualize its function. As students are drawn further in to the environment, their understanding evolves from high-level metaphor to lower-level mechanism, and they move from being metaphor consumers to metaphor producers. This transition from consumption to construction simultaneously marks an important step in their explorations of their Theories of Mind.

### 5.2 Future Directions

#### 5.2.1 Enhancing Genuine Object Orientation

The genuine object model in GOOP is fairly modest in its ability to integrate computation with physical objects. It could benefit from a more complete Object Oriented system that included things like class hierarchies and inheritance. For example, a community of students could maintain and extend a hierarchy of genuine objects. Computational behaviors that apply to all genuine objects would be located at the top of this hierarchy, such as default methods for behaviors when an object is first attached or detached. “Facial Features” could be a sub-class of this root category, with “Eyes” and “Mouths” sub-classed off of them. In this way, a student who wanted to build a

new mouth could declare it to be of class “mouth”, and then inherit a lot of default functionality for free. As students became more expert builders, they could make more general contributions further up in the hierarchy. The construction and maintenance of this class hierarchy could be an excellent exercise in community knowledge building (Scardamalia and Bereiter 1994).

### **5.2.2 Enhancing Knowledge Representation**

Although GOOP makes salient the encapsulation of knowledge in genuine objects, students must encapsulate this knowledge using a fairly traditional programming language. It would be interesting to create a language for children with more explicit knowledge representation features, borrowing from languages designed for this purpose such as Prolog. In this way, the structure of the knowledge frames that children build so characters like the Doctor can make sense of objects like the disco set (as depicted in Figure 3.3) would be made more salient.

A carefully crafted knowledge representation system could allow the Doctor to display evidence of having his own Theory of Mind. Currently, the Doctor has only modest knowledge of a student's or the Professor's knowledge; this type of knowledge is difficult to express in GOOPLogo. If a language made it easier to encode this kind of knowledge, then a student could actively construct and manipulate the Doctor's models of other people's models. Making this process tangible could help students reflect on their own such “meta-models”. and meta-modeling processes.

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