Embodied Cognition as a Motivating Perspective
for Haptic Interaction Design: A Position Paper

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ABSTRACT

In cognitive science and philosophy, the conception of cognition has evolved rapidly in recent years. It is no longer strictly a process that happens inside the head, intervening between perception and action. Instead, cognition is considered something that subsumes both perception and action, engages the body, and even incorporates the response of objects in the environment to actions taken upon them. One speaks of cognition being embodied and extended. Cognitive processes such as problem solving might actually involve the coupled dynamics of the body and the environment, where the finding of problem solutions involves interactively driving the coupled dynamics toward behaviors that satisfy the task goals of an individual. Researchers in haptics have long been working with the notions of dynamical coupling between the body and environment, with intertwined definitions of perception and action, and with flexible conceptions of the proximal and distal and the physical and virtual. It is perhaps striking to suppose that the activity during which our users wield our interface devices might be considered cognition itself. We suggest in this paper that the field of haptics is uniquely positioned to draw upon and to contribute to active debates in cognitive science, and that a new interpretation of ‘interface’ can be useful in launching such an endeavor.

1 INTRODUCTION

The body plays a central, even defining role in haptic perception. Most haptics researchers have pondered this role at one time or another, for the body is the scaffold for the haptic sense organs and it is the vehicle that mediates the coupling between perception and action. As the philosopher O’Shaughnessy notes: “Touch is in a certain respect the most important and certainly the most primordial of the senses. The reason is, that it is scarcely to be distinguished from the having of a body that can act in physical space.” [21] p.658, cited in Noe 2004 p.97. Active touch, haptic exploration—these are concepts that have long been central to the field of haptics and they depend on an awareness of body configuration and motion, and on the integration of sensory and motor capacities.

The defining influence of the moving body is something worth pondering in light of current thinking because the converse—perceiving without engaging in bodily movement—is not difficult to imagine. Indeed, the ability to experience and act on the world without a moving body seems to be what modern technology is driving toward. Through a computer, one can experience increasingly significant parts of the world without moving one’s body (or at least with very little bodily movement). Using only eyes on a screen and hand on a mouse or keyboard is enough to experience and even accomplish a great deal in the world today. Even beyond this, emerging brain-computer-interface (BCI) technologies allow one to control a cursor on a screen with absolutely no muscle action (Fabiani et al., 2004). All that is required in such situations is real-time monitoring of central (or peripheral) nerve signals by electroencephalography (EEG) or other means. It is not difficult to combine robotics and BCI technology to transform cursor control into performing physical work on one’s environment [14]. Following such a line of thinking, the ultimate computer interface it seems would be one that enables the functioning of the brain-in-a-vat—cognitive function and interaction that does not require a body [29].

On the other hand, the removal of the body as the means of mediating one’s interaction with the environment might be considered a regrettably direction for technical progress or even a preposterous expectation. Current computer interface technology has not been particularly focused on engaging the body in its multiple motor capacities and multiple sensory modalities. These shortcomings become particularly apparent when we push the boundaries of computer applications beyond tasks such as manipulating symbols (e.g. text editing) toward the manipulation of real or simulated environments (e.g. interactions with remote or virtual worlds.) The ‘Put That There’ interaction upon which the window-icon-menu-pointing device (WIMP) or desktop metaphor rests rapidly breaks down when ‘putting that there’ involves more than a pick-and-place task such as moving a file. In situations where not just what is moved but how something is moved becomes relevant such as, say, bowing a virtual violin string, it is necessary to consider not just an individual’s actions upon the environment but the way in which the environment and the individual are connected or coupled. It is not that a coupling does not exist in situations where one is viewing a screen and moving a mouse, but the physical coupling with the environment that is a necessary part of haptic interaction directly engages the body in simultaneous and coupled sensorimotor activity.

Even researchers in EEG-based BCI technologies are beginning to wonder whether the exceedingly long training periods (on the order of 20 hours) required to achieve even marginal proficiency at 2-axis cursor control might have something to do with the omission of the body’s haptic proprioceptive sense from the interface [3]. Whether re-engaging proprioception might reduce training times is a hypothesis that is attracting some interest now [13][24].

The question remains as to whether and how bodily movement plays a role in interaction with the computer, or more accurately, in interaction with the worlds brought forth (or synthesized) by the computer and its interface devices. While such a question is relevant for all sensory modalities that are utilized in human-computer interaction, haptic interaction and its associated interface technologies occupy a uniquely privileged position from which to ponder such questions. Forces can be reflected to mimic haptic interactions with objects, allowing them to apparently take on physical properties such as softness and behaviors such as inertia or resistance to being moved. Dynamic coupling between the body and environment can be re-established through haptic feedback. More importantly, as the hand is typically used both to explore the haptic environments we construct and is also typically the site of stimulation by the haptic displays we use, there is an opportunity to explore the role of action in perception, what Gibson termed the sense of “active touch” [12]. Such a line of enquiry is certainly not new to the field of haptics research. In fact, as several researchers have shown, allowing people to actively explore a virtual haptic en-
The environment can significantly alter the perceived realism of simulated haptic cues [18][17]. The question we pose here is whether the increasingly sophisticated applications for which haptics technology is being targeted are quickly outstripping the science available to explain the phenomena that underlie the function and utility of haptic cues. Certainly we have amassed a significant body of science in psychophysics and haptic perception which has rightly informed and guided the development of technology within the field of haptics. Here we propose that the science we must bring to bear on our broadening suite of applications should itself be significantly broadened. One direction to explore is neuroscience and the associated body of work on neurophysiology. Such explorations are beginning to shed much light on the relationships between motor activity and sensory response within and across sensory boundaries e.g. for texture perception [25].

We suggest here that there exist additional fields whose hypotheses, results, and tenets could be brought to bear on the field of haptic interaction with computationally mediated environments. Specifically, we take a look at ideas emerging from the field of embodied cognition and the related domain that has been called the “enactive approach” to perception and action. We focus on the implications that the embodied cognition perspective might have for the field of haptics and its possible future directions. The users of our haptic devices are not simply perceiving. And they are not applying actions strictly to serve active touch. They are acting on the environment to which they are coupled, sometimes acting as agents effecting change, and they are attributing meaning to what they feel. We propose that a framework for understanding cognitive processes, then, should also be of concern for the haptic interaction designer. The haptics community is in a very privileged position to engage the body of work on neurophysiology. Such explorations are beginning to shed much light on the relationships between motor activity and sensory response within and across sensory boundaries e.g. for texture perception [25].

The role of the body in perception and in the process of cognition has been a theme around which some very active debates have recently developed in the fields of cognitive science, psychology, and philosophy. Insofar as all perceptual experience is mediated by the body and its sense organs, cognitive scientists have spent a great deal of time pondering the function of the body in the formation and processing of conscious thought. The philosopher Alva Noé even goes so far as to suggest that touch is the paradigmatic sense and that vision, far from being passive, is more akin to touching the world with one’s eyes (See Noé p.96 and following.)

The term ‘embodied cognition’ has been coined to indicate a definition of cognition that is extended to include bodily interactions with the world. This viewpoint stands in direct opposition to the more traditional definitions of cognition as primarily an abstract, rule-based manipulation of symbols that takes place solely in the head. Hurley for example, suggests that familiar views of the mind posit that perception and action are separate from each other and peripheral, while cognition or conscious thought forms the central core of the mind, a construct which she refers to as the ‘classical sandwich’. Moreover, from this perspective, perception and action are not just separated from each other, but are separated from the higher functions of cognition, so that the mind decomposes vertically into modules where cognition interfaces between perception and action (Hurley, 2001). One could say that, from this viewpoint, the sensory apparatus is held to be responsible for informing the problem-solving brain about the current states of the environment and the motor apparatus is the means of expressing the solutions, the plans that the brain comes up with. It can be argued that this conception of the brain has been influenced by the emergence of the computer, in that the computer and computer programs are largely designed to operate on symbols according to algorithms that seek solutions to problem statements, also formulated in symbols. Algorithm inputs may include sensed variables and outputs may produce motor action through robotic extensions to the computer. On the other hand, computers have achieved a great deal given this conception. Given this success, it can be argued that the “disembodied” cognition viewpoint is very successful.

But this traditional conception is being increasingly challenged by embodied cognition. Proponents of embodied cognition would say that what we are striving for is sensorimotor coupling with an environment (real or virtual) and that computational devices represent tools that mediate this coupling. In this respect, what we require of these tools is that they provide a reliable coupling to the task environment that we are constructing. If that task requires us to manipulate or respond to physical properties in the environment, then these must be represented in an appropriate way—seeing arrows on a screen that portray the forces that are being applied to a telerobotic arm at a distant site does not provide the most appropriate sensorimotor coupling to that task—we need to feel what is happening if we are to build upon an embodied understanding of the interaction dynamics.

This approach to cognition has recently attracted the attention of the field of human-computer interaction, taking the form of a design approach called ‘Embodied Interaction Design’. Embodiment, as reflected through the lense of HCI has a very specific meaning, as it encompasses not just the embodiment of physical objects such as tables and chairs, but also embodied actions such as gesture and speech. Embodiment represents, for practitioners such as Dourish, the transition from the relm of ideas to the relm of physical experience, from thinking to doing [9]. With respect to the ideas that are central to this current paper, this approach does not go far enough, as it fails to consider the fundamental role of the coupling between perception and action in the experience of the person ‘acting’ within such an environment. For this reason, we turn to the work on ‘En-action’ which gives primacy to a notion of embodiment that places the body of the perceiving, acting person at the centre, embedding them within a much broader biological, psychological and cultural context where the interaction with any computational device is no more privileged than the interaction with any other artifact or tool. The Enactive Approach to perception and action has roots in three separate but related places - in the work of Jerome Bruner on ‘enactive learning’ [5], in the dynamic sensorimotor approach to perception and action of Noe and O’Regan [20] but most centrally in the work of Varela and his colleagues [27]. Varela emphasises the fact that the perceiving, acting individual does not operate in a vacuum, but within a world where they are trying to accomplish a series of goals. And central to this approach are the experiences of the individual and the meaning, for the individual, of these experiences. Marek McGann, in a recent briefing to the euCognition project, elegantly states the subtle nature of the shift in thinking suggested by the enactive approach as follows:

Cognition is a bit like a handshake. You can’t make a handshake by yourself, and you can’t really do it by accident. Handshakes involve reaching, and they involve a rather subtle form of negotiation: how firmly do you grip? How many pumps? How long do you hold on before you let go? Once you know how to shake hands though, you can do lots of interesting things, such as decide whether the person you are shaking hands with is...
confident or timorous, friendly or suspicious, interested or disdainful. So it is between you and the world in the case of cognition [19].

It is therefore better, McGann suggests, to think of cognition not as an abstract process that takes place in an isolated mind, but as a skilled activity requiring both the individual and their environment. See also [11] for an interesting experiment involving virtual handshakes.

Reframing cognition as a skilled activity that relies on a person being embedded in, and coupled to an environment has implications for designers of haptic systems which are indeed far-reaching. The first of these is the implication that, because an acting person is inevitably engaged in moving, the coupling between the person and the environment is a dynamical coupling. Energy is exchanged between the individual and the objects upon which they act and both the flow and direction of this energy fluctuate over time. Claude Cadoz, in developing the concept of the ‘instrumental gesture’, a way of describing the interchange of energy between a musician and an acoustic musical instrument, coins the term “Ergotic Function” and suggests that it represents a modification of the material properties of the musician/instrument environment (Cadoz and Wanderley, 2000). For Cadoz, the gestures performed by a musician carry the signature of the characteristics of the physical system being controlled—the gliding motion that results from drawing a bow across a string, the striking gestures of the percussionist, and so on. Thus, when viewed over time, the dynamic signature of the person/environment coupling encapsulates the dynamics of the individual, the environment, and the coupling between the two. Taken to its conclusion, this line of reasoning leads to the important realisation that the information available to the user of a haptic system is not ‘represented’ in the simulated environment, but arises as a result of an exchange, over time, of energy between the person and the environment that happens to contain a partly simulated experience. It is the skilled action of the person using the system that gives rise to their cognition of the situation, not the presence of ‘information’ as some sort of abstract component embedded in the interface itself.

The second implication of McGann’s statement is that cognition not only expects, but fundamentally requires the person and the environment to be coupled. If cognition arises from an exchange of energy between the person and the environment it follows that, in the absence of the possibility for such an exchange of energy to occur, no new knowledge can be acquired. The open question for embodied cognition theorists is how prior experience can inform current action, i.e. what is retained for later recall. Most proponents of embodied cognition reject the notion of the presence of a complete, internal representation of the world, suggesting that the world is its own best model, as the environment in which we act itself shapes and guides our actions (see, for example, [20]). If we allow that such an argument holds, at least for cognition that is predicated upon action (as opposed to abstract manipulation of, say, words or numbers), then we arrive at the realisation that we, as haptic designers, are truly engaged in ‘interaction design’, because we are building the potential for the interaction between a person and an environment, coupled through our artifacts, to give rise to the acquisition of new knowledge, thereby supporting cognition through action.

This is all very well in theory, perhaps, but how can this inform the way we design haptic interfaces? In the following section we suggest that the change required is primarily in how we think about the experiences that the users of haptic devices and their associated environments have when they interact with and through our interfaces. In fact, as we will suggest, this may require us to dispense with the notion of ‘interface’ altogether.

## 3 A FRAMEWORK FOR REPOSITIONING THE BODY IN HAPTIC INTERACTION

Many interfaces that are not explicitly defined as invoking the tenants of embodied cognition are, in reality, required to do so by the nature of the tasks they support. Thus devices such as telemanipulation systems and collaborative robots represent systems which allow an operator to act in an environment at a scale or at a distance that is beyond their reach. Augmented prosthetic devices too allow their users to effect actions on the environment [28] while sensory substitution devices must support a user in learning to act on and perceive the world through a mediated interface layer [2].

An important question raised by the foregoing discussion of embodied cognition is what happens to the notion of ‘interface’ within an interaction paradigm that rests upon the coupling between the user of a tool and the environment upon which they are acting? To answer this question, it is necessary to address the notion of what the term ‘interface’ in this context means. The HCI community has placed much emphasis on the notion of ‘transparency’ of the interface with the implicit goal that the interface to a computer should ‘disappear’ from the awareness of the user (see, for example, [10]). Likewise, the notion of transparency holds much traction in the haptic field. The philosopher John Stewart goes further stating that:

As we understand it, the term “interface” is properly used as the interface between an organism (human or otherwise) and its environment. Thus, the basic “interfaces” are the biological sensory and motor organs; for humans, technical artifacts are extensions to these basic interfaces, but they remain interfaces. New technical devices constitute new “worlds”: think for example of the “world of the car-driver”, or the “world of the skier”, or the “world of the violinist”. But note this: we do not talk about the “interface” between the man and the ski (or car or violin); the ski is the interface between the man and the snowy mountain, or better still between the skier and the “ski-ing world” that is brought forth.

Does this change in the case of computers? Our point of view is that computers are basically technical devices, and should be treated in the same way as other technical devices. Certainly, they are devices of a special sort, and the “worlds” that are brought forth when a human being uses them are a special sort of “world”; but the interaction that occurs (that is mediated by the machine) is between the human being and this “world”; it is not an interaction between the human being and the machine. Thus, there is something deeply wrong in the very phrase “Human-Computer Interface” [26].

The crucial shift in thinking here is to realise that the human-computer interface is not privileged, but is merely an instance of an interface between a human organism and its task environment that is computationally mediated. It coexists with other instances of ‘interface’ between the user and the environment - the person/seat interface, the foot/floor interface, and so on. Stewart provides a useful framework into which the technical artifacts we create can be placed, a framework which articulates their positioning within the coupled person/environment system. He identifies three categories [26]:

1. Extensions of the body - tools and augmentations to sensory systems that extend one’s reach both in scale and scope.
2. Augmentations to the environment - augmentations that facilitate the use of the technical artifacts we create (e.g. roads for cars, houses for living in, and so on.)
3. Semiotic artifacts - where the ‘actions’ performed consist in the emitting of signals that are meaningful to another organism specifically tailored to respond to or ‘sense’ these signals.
In short, Stewart’s thesis is that all technical artefacts, “from stone tools to cars to computers, are ‘enactive interfaces’ that mediate the structural coupling between human beings and the world they live in, and hence bring forth a particular world of lived experience.”

For the purposes of this current paper, it is more useful to think of Stewart’s formulation not as a series of mutually exclusive categories, but as a conceptual framework, a scaffolding for thinking about different facets of haptic interaction with mediated or constructed environments. It is then possible to notice how, for example, a telerobot functions to extend an operator’s reach into a distant environment, or the role that constructs such as virtual fixtures play as modifications to an environment that can help to guide a user’s actions. It cannot be emphasized enough, though, that such categories do not exist a priori, but emerge over time as a user becomes skilled in using a haptic device. As stated above, the individual’s goal is always to seek meaning through their interaction with the world, so that the role that our devices and simulations are taking on is fundamentally one of supporting a user in achieving their task goal.

Think, for example, of the user of a sensory substitution system. Auvray et al (2005) suggest that there are several aspects to acquiring skill in the use of a sensory substitution ‘tool’ so that it can function to support the person in their task of exploring the world through a new sensory modality - the ability to recognise the coupling between their action and the system’s response, the ability to individuate objects external to their body, and the ability to recognise the existence of a perceptual space beyond the boundaries of their body. Crucially, they suggest that the recognition of the coupling between action and response has to be established before objects and external space can be disambiguated. These findings support the notion of emergence, suggesting that the individual’s understanding of the relationship between their actions and the response of the tools they are using is the key to the emergence of other aspects such as the awareness of modifications to the environment and the attribution of meaning to any component of their interaction with the environment.

4 OPTIONS FOR POSITIONING A MOTORIZED DEVICE IN HAPTIC INTERACTION

Since the earliest work on computerized haptic technology, haptic devices and force-reflecting teleoperators have functioned as extensions of the body. They allow the projection of agency and the conveyance of sensory feedback between the user and virtual or remote environments. With suitable augmentations, they have functioned to project the body through scale changes and to sharpen the senses. However, haptic devices are occasionally employed under different guises—guises that do not fall into the first of Stewart’s categories, extensions of the body. The virtual fixture can be recognized as an extension to a remote environment that simplifies the task (second category). Certain applications employ haptic devices as semiotic artifacts (third category), where the intention is to display symbolically coded information, and the approach is to encode that information into recognizable haptic icons or hapticons [6].

Somewhat independent of the category into which the artifact falls, there are various means by which a haptic device might be used to couple a user to an environment, and various senses in which the term ‘coupled’ might apply. Certainly ‘coupled’ implies the existence of bi-directional signal flow, two-way communication. But whether the coupling also supports non-trivial mechanical power flow is an additional qualification that is very pertinent to the haptic interaction designer. In interaction with objects in the physical environment, the context always includes a mechanical contact, at which point force and motion variables can be identified, and across which power may flow. In interaction with objects in a virtual or remote environment, it is not necessary for the contact across which haptic responses are rendered to be the same as the contact at which exploratory actions are applied [4].

In practice, the qualities of coupling most likely differ by artifact category, that is to say, it will depend on whether the device extends the body, modifies the environment, or functions as a semiotic artifact. Here we shall attempt to delineate these qualities. In the discussion above, we have suggested that cognition can be seen as a process of engaging in dynamic interaction with the environment. That is, the simultaneous engagement of perception, action, processing, and the coupled dynamics of the body and environment together make up what we should appropriately label cognition. If we accept Auvray’s suggestion that a necessary feature for the suitable function of an interface (one supporting such functions as distinguishing figure from ground) is the existence of a recognizable relationship between action and response, then it seems that coupling between the perceiver/agent and the environment is required. But only in the case of action and response being transmitted across the same mechanical contact is coupling necessarily associated with power flow. We feel that this question is vastly underappreciated by both the interaction design community and the communities grappling with embodied and embedded cognition.

In mechanical system modeling, the term ‘dynamical coupling’ or ‘dynamical interaction’ has a very specific meaning and includes certain pre-requisites that will be very useful to elaborate here. These interpretations of the term ‘coupling’ apply only to certain aspects of the application of a haptic device. While it is conceivable that all three of the Stewart categories might involve dynamical coupling in the specialised sense outlined below, we will argue that the most natural application of this term is in the case of the extension of the body.

In particular, dynamical coupling between two mechanical systems is established when those systems make mechanical contact with one another. At that point of contact, the quantities force and velocity may be defined (and possibly measured) and energy may be exchanged between those systems. The energy exchanged is the accumulated power, which in turn may be quantified as the product of the force and velocity that co-occur at the point of contact. These notions of dynamical coupling have been richly explored in the modeling and analysis of haptic devices, most notably by [8, 23, 15, 1].

An engineering model of the mechanical contact between a user and a device such as a teleoperator (and likewise the contact between the device and the remote environment) will make explicit a multiplicity of feedback loops that underlie dynamical coupling. In control engineering terms, each mechanical contact closes a feedback loop. Associated with that loop closure are the two quantities force and displacement (or the two power-conjugate variables, force and velocity). In the control engineering model, these quantities are called signals and as a consequence of the feedback structure, they are necessarily directed opposite to one another. Note that it is by virtue of the mechanical system model that they co-occur at a single contact. They are co-located. If a tool or other artifact that functions to extend the body is imposed between a user’s hand and the object, we would model that tool as a two-port [16, 22]. It makes one contact with the user (establishing a first port) and another contact with the object (establishing a second port). The most general two-port model contains a network of four transfer functions coupling the signals associated with either port, and each of these transfer functions may carry dynamics, or have an output that depends on input history.

Figure 1 shows a two-port model of a teleoperator interposed between a user’s hand and a simple single-axis torsional spring. This two-port model has been elaborated with four named transfer functions and a causality or signal direction has been assumed at each port. Thus in this model, what the user feels in response to a torque he imposes on the teleoperator master is an angular velocity \( \dot{\phi}_1 \) that is the sum of two components. The first component is due to the
transfer function $\frac{\Omega_1}{\tau_1}$, which is the driving point impedance of the teleoperator. The transfer function $\frac{\Omega_1}{\tau_1}$ expresses a dynamical relationship between $\tau_1$ and $\omega_1$ or an invariant that can be discovered through haptic exploration. The second component of $\omega_1$ is due to a cascade of $\frac{T_1}{T_1}$, the feedback interconnection of $\frac{T_1}{T_2}$ and the spring $\frac{1}{T_2}$, and finally $\frac{T_2}{T_2}$. Basically, there is more than a single “loop” or pathway that relates the torque $\tau_1$ that the user imposes and the response $\omega_1$ that he feels. One pathway is due solely to a portion of the teleoperator dynamics and the other is due to the coupling between the remaining portions of the teleoperator and the environment. In a similar manner, one could study the model to determine what the environment “feels” of the teleoperator and user, and this duality is part of what underlies dynamical coupling.

One could take this approach a step further. Why not model the mechanics of the user’s body as a two-port as well? Certainly the mechanics of the body are also subject to the laws of Newton. A “port” might even be identified between the ascending and descending peripheral nerve signals and the body, where the muscles would play the role of actuators and the body’s haptic receptors (muscle spindles, Golgi organs, and cutaneous receptors) would transduce between mechanical quantities and nerve signals. A candidate model is also presented as part of Figure 1.

When both the biomechanics of the body and the teleoperator are laid out as two-port models, the richness of dynamical coupling is immediately recognized. The viewpoint that perception and action are distinct processes that occur at separated points in time cannot be supported in such a model. It is not even the signals alone that hold the information of interest to the brain, it is the relationship between them. In this particular model of haptic exploration of a spring, it is the stiffness of the object under exploration. The signals are certainly not carried by sequences of symbols whose semantics and use establishes meaning. Instead, they are continuous-time consequences of dynamic interaction. Action and perception become mutually interdependent processes serviced by the body and those artifacts chosen and wielded as extensions of the body. Probing the torsional spring with an applied torque is required before excursions in the response motion can be gathered. Together, the applied torque (or efference copy or memory thereof) and the observed motion response hold the information pertaining to stiffness. Naturally, the causality could be reversed: the user could be modeled as applying motion and monitoring the response torque. The feedback structure is an integral part of the process of extracting information (content) and of integrating perception and action.

5 IMPLICATIONS FOR THE DESIGN OF HAPTIC INTERFACES

The proposition that cognition is itself a process that involves the body and the body’s interaction with the environment has huge implications for the haptic interaction designer. It places the haptics project into the forefront of human-valued activities. Haptics technology spans a very broad range of applications, and across these applications haptic cues are synthesized to serve rather diverse functions. A force-reflecting teleoperator is generally intended to function as an extension of the body, transporting motor capacities and mechanical sensory cues between a local and remote site. Haptic or tactile icons, on the other hand, do not fit the description of “body extenders” particularly well. Tactile icons have a closer relationship to elements of visual or verbal language, requiring recognition and interpretation from a user and having little to do with transporting manual skill into remote or virtual environments. Then again, haptic devices intended for sensory substitution are neither displaying elements of language nor functioning as body extenders like teleoperators.

Here we have suggested that it is possible to relate these different roles or facets of haptic interaction within a framework derived from Stewart’s categories of technical artifacts, as long as these labels are not taken to be mutually exclusive, but considered as aspects that can emerge to varying degrees within any computer-mediated haptic environment.

A second point that emerges is the notion that interface is itself no longer relevant in a mode of thinking that affords no privilege to the computer-mediated artifact over and above any other tool or artifact. A computer-mediated tool, like any other tool, either succeeds or fails in supporting a user in achieving a goal. Letting go of the notion of interface is both challenging and liberating—challenging because we must relinquish the role of the designer in controlling the user’s experience—in deciding what information is or is not transmitted in such a context; liberating, particularly for the field of haptics, in that it frees us to concentrate on the experience, the ‘feel’ of the world we can create for the user.

Finally, by focussing on the experience a user gains through their coupling to a haptic environment, we can think anew about what it means to become a skilled user of a tool. Unlike the field of HCI in general, where much emphasis has been placed on supporting
the ‘un-skilled’ user, we can make a stand for skill as a necessary component of proficiency and of real engagement with haptically enhanced computer-mediated tools and environments.

6 Conclusion

In this paper we have made the bold claim that there is no such thing as ‘a’ haptic interface. Haptic interface is not a touchable thing at all. It is a layer that supports the interaction between two subsystems and thereby gives rise to a new coupled dynamical system. That new dynamical system supports the concurrent and co-dependent processes of perception, action, and cognition that take place partly in the brain but also take place in and involve the body and the task-world that is brought forth through interaction. For our users, the devices we design (those gizmos we now refrain from calling ‘interfaces’ when they stand alone) are intimately involved in establishing the interaction dynamics—as intimately involved as the body. What transpires through interface is the acquisition of content or knowledge regarding the environment or task-world. What transpires is meaning-making and skill acquisition. Sometimes what transpires is change in the environment and sometimes even change in the brain (see [7]).

In attempting to align the concepts of dynamical coupling as interpreted in the domains of embodied cognition and engineering, we have drawn attention to certain subtle distinctions. We believe that whether, in addition to supporting bi-directional signal flow, the interface supports the exchange of mechanical power, is an important distinction of concern to the haptic interaction designer. Exchange of power can take place when the coupling is instantiated through force and motion signals at a single contact point (port) between user and haptic device. The device is only an interface, intervening between the user and the virtual or remote environment, and is thus modeled as a two-port. Note that the distinction concerning power flow is not necessarily aligned with the distinctions between Stewart’s artifact categories.

Our intention in this paper has been to inspire new work in the field of haptics. We maintain that many of the applications for haptics technology that we are now pursuing will require a new understanding of interface and its role in cognition. We have attempted to introduce the haptics community at large to some of the work in enaction that has already produced measurable fruit of value to the interaction designer. Further, we think that the haptics community is better positioned than most any other scientific or engineering community to enter the fray of ongoing debates in cognitive science and philosophy and to contribute empirical evidence with which some positions may be tent support and others may be refuted.

References


