

Dance-Inspired Technology, Technology-Inspired Dance

Berto Gonzalez
agonza32@uncc.edu

Erin Carroll
e.carroll@uncc.edu

Celine Latulipe
clatulip@uncc.edu

HCILab
University of North Carolina at Charlotte
Charlotte, NC 28223

ABSTRACT

The design of interactive dance is a challenging endeavor because both dance and computing are in themselves full of complexity, thus to create a cohesive union of the two involves much trial and error and a mutual disciplinary understanding. Since interactive dance is a performing art, technologists working as designers must consider how all of the parts – choreography, media, interactivity – are integrated to inform the overall gestalt and intent of the piece. To this end, we offer five design principles for making interactive dance: *Connected Kinetics*, *Augmented Expression*, *Aesthetic Harmony*, *Interactive Build*, and *Integrated Process*. These design principles have emerged from our practice-based research in collaboratively producing six different interactive dance pieces over the past four years.

Author Keywords

Interactive Dance, Design Principles

ACM Classification Keywords

H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

General Terms

Design, Human Factors

INTRODUCTION

True interdisciplinary research should demonstrate an exchange of ideas, practices, and perspectives among researchers and practitioners. As experts from one domain engage deeply with experts from another, a process of learning and acculturation takes place. This process can involve conflict, and not every person will take equally to the other field. Harmony emerges as experts from one domain learn enough about the other domain to make contributions with recognizable value in that other domain. The interdisciplinary work presented here involves computer science researchers working with dance practitioners in creating interactive dance performances. This work demonstrates how our understanding of designing interactive dance (i.e. research) emerged

through the creation of performing arts pieces (i.e. practice). During this process, our dance colleagues became significantly more technical savy, while we gained a significant understanding of the intricacies of dance, choreography and performance. Our contribution is a set of case studies illustrating the complexities of interdisciplinary work between computing and performing arts, and a set of design principles to serve as starting points for others planning similar collaborations.

In formal dance, there exist subtleties that typical audience members may not be conscious of, such as the particular bend of a finger or the emotional intent of a gaze. These subtleties are often emphasized and fine-tuned by the choreographer during rehearsals. Consider this scenario: dancers stand in a circle and each places a hand one on top of another. All together they lift their hands into the air, moving on to their respective phrase work. The choreographer makes a change: one dancer will continue lifting her hand into the air, rather than pulling away with the other dancers. This subtle difference promotes a feeling of lifting instead of just moving upward. Every successful dance performance is made up of many seemingly minute decisions such as this. When technology is introduced into the formal dance production process, a new set of considerations emerge for the choreography and the dance piece as a whole. While most choreographic principles and practices still hold, the integration of interactive technologies necessitates modifications to the creative process and some adjustments in artistic goals.

In this paper, we present a set of five design principles that address some of the critical challenges when making interactive dance. These design principles have emerged from our experience in creating numerous interactive dance pieces over the last four years. This practice-based research was conducted collaboratively by a group of computer scientists, choreographers, and dancers. We describe how these design principles emerged through a series of six dance production case studies. Then, we relate the principles to others who wish to integrate interactive technology into their respective practices. We expect these principles to be useful as starting points or goal considerations for researchers and practitioners wishing to bridge computing and the performing arts.

RELATED WORK

Interactive Dance

There is an active community of dancers and choreographic practitioners who are experimenting with dance and technology integration and the use of technology to engage audiences, as evidenced by the enthusiastic participation and

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. To copy otherwise, or republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee.

NordiCHI '12, October 14-17, 2012 Copenhagen, Denmark
Copyright 2012 ACM 978-1-4503-1482-4/12/10...\$15.00

lively exchange on web sites such as dance-tech.net. Kent deSpain has also described a number of notable performances that integrated dance and technology [4].

Within the academic research community, interactive dance has been explored with a variety of different technologies and approaches. Faver used a live video feed of dancers [6]. Both Meador et al. [15] and Mandilian et al. [13] used motion capture, silhouettes, and video filters in their dance productions. Sheppard et al. found creative ways for computer scientists to work with dancers through tele-immersive dance [18]. In previous work, we have used various sensing techniques to track dancers' movements [11, 9] and have written about the temporal aspects of technology integration [10].

Mark Coniglio, founder of the interactive dance company Troika Ranch, has also used dancers' movements to control media elements [2]. He advised that dancers should have some room for improvisation in order to take full advantage of the interactivity. He also suggested that the audience have some understanding of the dancers' interaction with the technology. Dancer improvisation can be an important part of the rehearsal process, but does not necessarily need to be part of the final performance unless part of the artistic intent. Our work expands on Coniglio's idea of audience understanding and offers other relevant principles.

Loke and Robertson have investigated dance as a foray into understanding kinetic, aesthetic experiences and how they can translate into richer, more embodied, interaction design [12]. Their work has a different goal of learning from the skilled moving body to understand how best to deploy motion-sensing technologies. They work from the perspective of the dancers, focusing on the felt experience of the dancers. In related work, Reason and Reynolds investigated the kinesthetic experiences of dance spectators [16]. In a similar fashion, Corness et al. investigated technology-mediated dance in an intimate, informal setting as a way to build audience empathy [3]. Our discussion differs in that we establish principles for creating interactive dance by combining the experience of the technologists taking part in the world of dance with reflections from the dancers and choreographer.

Art Installations

Interactive art installations share certain similarities with interactive dance: both involve the embodied participation of individuals with digital technology in a prescribed space, with some type of artistic or educational goal. Both involve an audience, though in the case of art installations, audience members can become the participants or performers, which is not typically the case in formal dance. Thus, it is appropriate to consider whether design principles can be borrowed from interactive art to inform the practice of interactive dance. Vogel et al. have looked at social interaction with interactive displays and issues around proxemics [21]. However, this work does not specifically address art and performance. Drawing from his own interactive installations, Snibbe introduced six design principles for social immersive media, which he defines as "immersive media that favors interaction in a shared social space using a person's entire body as the input de-

vice [19]." He recommends that social immersive media experiences be Visceral, Responsive, Continuously Variable, Socially Scalable, Socially Familiar, and Socially Balanced.

In our work, we expand upon Snibbe's design principles as they apply to a more formal practice of interactive dance. The first three principles, Visceral, Responsive, and Continuously Variable, are all highly relevant to the design of interactive dance. Visceral focuses on how media is first experienced physically and emotionally before it is experienced symbolically or rationally. Social immersive media should be Responsive to the user's actions and Continuously Variable, having a dynamic quality. Snibbe's other three social principles are related in more subtle ways, as interactive dance within a formal setting does not typically involve explicit participation of the audience. Researchers involved in less formal dance settings that encourage audience participation could benefit from a more direct application of Snibbe's principles of social interaction as well as the work of Maynes-Aminzade et al. on various techniques for audience participation [14] and the work of Reeves et al. for designing for crowds [17].

DESIGNING INTERACTIVE DANCE

The design of interactive dance must be approached cautiously because first and foremost, we are creating dance, and as a performing art, in order to inform the overall gestalt, thoughtful consideration must be given to all parts: the choreography, the visualizations, the interactivity, and the integration of technology and choreography.

An important distinction between art installations, and interactive dance is the notion of the user. In art installations, the design focus is placed on how the users interact with the installation. However, designers of interactive dance must not only design for the dancers' interaction with the interactive media, but must equally consider the intent of the choreography and how the dance will be experienced by the audience.

Design Principles

From our practice-based research, we present five design principles for making interactive dance.

Connected Kinetics Audience members should be able to tell that dancers' movements control, manipulate, or influence the kinetics of the visualizations.

Augmented Expression The technology should enrich the mediums of expression available to the choreographer and dancers or provide entirely new mediums of expression.

Aesthetic Harmony A relationship should be established between the dancers and visualizations such that they complement each other to create an integrated aesthetic.

Interactive Build The variability and intensity of the visualizations and interaction should progress throughout the dance to match the build of the choreography.

Integrated Process The technologist should be integrated into the choreographic design process to better inform the development of the technology, visualizations, and choreography to support their subsequent union.

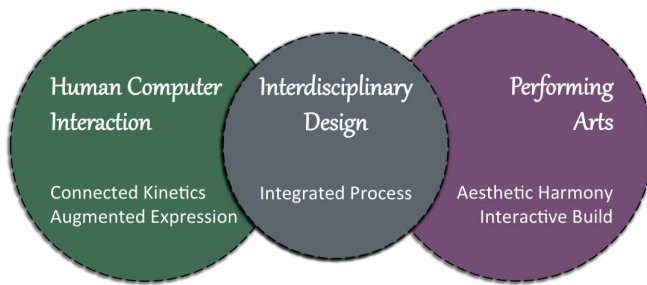


Figure 1. Familiar principles are rooted in respective fields/traditions.

Some of our principles were implicit design goals from the beginning of our project, and became more explicit and better understood over time. For example, the principle of *Aesthetic Harmony* implicitly arose as a design goal in our very first dance as part of the choreographic production process, which looks at how every piece of the performance fits together. Initially, *Aesthetic Harmony* was naively framed as a goal of equal balance between the attentional demands created by the dancers and the interactive visualizations. However, as we became more experienced in making interactive dance, this goal of equal balance evolved into a more nuanced and sophisticated seeking of an overall aesthetic gestalt.

We did not initially start out with the idea of needing our visualizations to have *Interactive Build*, rather it was implicitly achieved while trying to follow the build of the choreography. For example, if the choreography has re-occurring elements (e.g. specific movements, a maverick dancer) that build up to a conclusion, the visualizations should follow a similar build (see *The Angled Angels Assembly*). As *Interactive Build* became more explicit, we found it to be an expansion of Snibbe's principle of continuously variable [19]; taking into account the different temporal nature of formal dance. While interactive art installations may be visited by participants for a few seconds or a few minutes, a formal dance can last up to 20 or 30 minutes. This implicitly necessitates that the interaction change and adapt to the context of the dance over time. Thus, while infinite variability certainly contributes to the build of the visualizations, interactive dance must also showcase a variety of visualizations with many different interaction techniques, in line with how a choreographer develops and incorporates build in her dance.

Connected Kinetics was an initial goal and is built upon Snibbe's principles of responsive and visceral media [19]. Unlike art installations, dance audience members are not usually given the opportunity to experiment with the visualizations and technology to figure out the interactive mappings between them. While responsiveness of the visualizations is important to the dancers, Hook et al., in their work on interactive VJing, described responsiveness for the audience as an important theme [7] as well. Since interactive dance is a performing art, we were concerned with the audience's perceptions, wanting them to have a visceral reaction to both the visualizations and the choreography.

Because there is a history of audience members seeing recorded video projected behind dancers [15] and large screens are typically used for showing movies, the goal of *Connected Kinetics* is to convey to the audience that the dancers are controlling the visualizations in real-time through their movement and not just performing in front of pre-recorded video. This real-time interaction is one of the aspects of interactive dance that is so compelling: given that dancers will move slightly differently or may improvise, the visualizations will differ between performances and so each audience will see a unique interactive performance. The interactive components of the dance are very much alive, and given the effort required to produce them, it is important to those involved that the audience be able to appreciate that.

The last two principles, *Augmented Expression* and *Integrated Process* were not principles that we implicitly or explicitly expressed in our early dance performances. Rather, they emerged through our practice-based research as by-products of situated action [20]. Under *Augmented Expression*, there are two parts to a technology: the intended application and the usage that results from exploration. When we first introduced camera tracking, we found we were able to not only track the dancers in real-time but also relieve some of the movement limitations and stress that comes with using held or embedded technologies. At the same time, the team discovered that showing filtered or even raw video feed could contribute to the artistic intent. This use of live-video from a camera is not new, what's important about *Augmented Expression* is creating environments that foster this sort of discovery where the technologist sees a technology for more than its designed or typical use and the choreographer can push the limits of technology.

Principles *Connected Kinetics* and *Augmented Expression* will feel intuitive to researchers in HCI, while *Aesthetic Harmony* and *Interactive Build* will resonate with practitioners in the performing arts. In this union of traditions, some choreographers may feel apprehensive about including new technologies into the production process [1] and some technologists, who are accustomed to hard science, are venturing into unfamiliar territory (i.e. more aesthetic) through situated action [20]. It's not surprising that tensions arise between artistic intent and research goals. Early on there were clear distinctions: the technologists had most of the say in how the technology would function and the choreographers were the only ones who could really comment on the art. It is the final principle, *Integrated Process*, that helps us revisit familiar paradigms and resolve them to functional paradigms, see Figure 1. It is through *Integrated Process* that we've seen choreographers give great insight into how a technology functions and we've seen dancers and choreographers ask for the technologist's opinion on when a movement phrase should occur.

DANCE PRODUCTION CASE STUDIES

As technologists and choreographers working together, our interdisciplinary team has developed nine interactive dance productions over the course of four years – six of these dance productions are described here as case studies (Table 1).

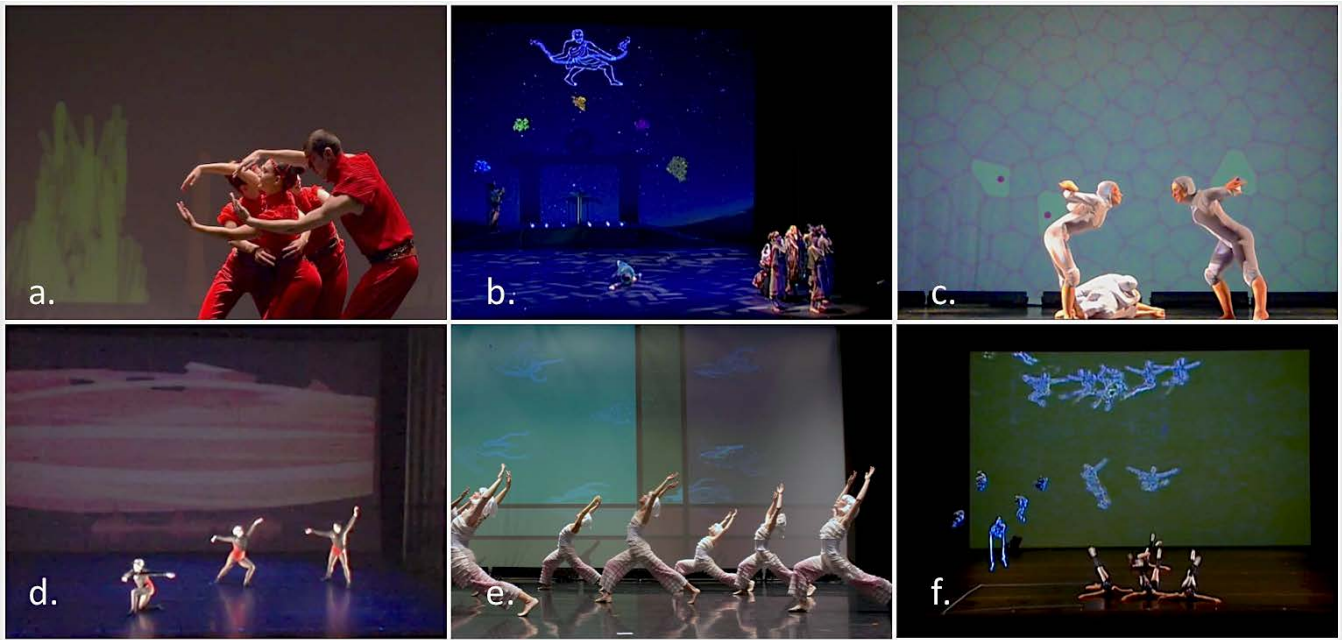


Figure 2. a) *A Mischief of Mus musculus* b) *Whispering to Ophiuchus* c) *Bodies/Antibodies* d) *An Instance Of...* e) *The Angled Angels Assembly* f) *Heavy Recursion*

While produced within a university setting, these dance productions are not just research prototypes; they have been staged as live performances in front of substantial audiences within formal dance concert settings and are part of the academic dance curriculum at our institution. These productions have had to fit within the context of the existing practices, facilities, and social norms of the academic dance setting at our institution. Thus, the principles described throughout the case studies have clearly emerged through situated action [20]. Throughout the process of making interactive dance, we have experimented with many different design goals, during which we have identified successes and failures through team reflection, audience surveys, and focus groups with dancers. In this section, we present six interactive dance productions as case studies through which we derived our five design principles for interactive dance. We describe each dance production by discussing the technology and team composition in each dance, highlighting how each of our design principles emerged and impacted subsequent dance productions.

Dance 1: *A Mischief of mus Musculus*

The first interactive dance production was called, “*A Mischief of Mus musculus*” (Figure 2A). Our team consisted of one choreographer, one technologist, and one visual artist who all worked together and attended the dance rehearsals. The visual artist generated ideas for visualizations, inspired by both his artistic vision and the choreography. He also worked closely with the technologist, both inside and outside rehearsals, to make the visualizations interactive. The technologist contributed ideas for interactivity based on observations of the choreography. The visualizations were controlled by the dancers’ movements using wireless, gyroscopic computer mice that dancers held in their hands.

An early concern was that the visualizations would be distracting to audience members by overpowering the dancers. Thus, it was one of our design goals to attain *Aesthetic Harmony*. In particular, we focused on the notion of achieving an equal attention balance between the visualizations and the dancers by creating interactive visualizations that matched and echoed the energy and movement of the choreography and the number of dancers on stage at any time.

We also recognized that it was crucial for the interactive visualizations to extend beyond Snibbe’s recommendations of being continuously variable and responsive [19]. Much in the same way that choreographers develop and incorporate build into a dance, it was equally important for our visualizations to evolve as the eleven minute dance progressed. Therefore, we implicitly incorporated *Interactive Build* by creating an assortment of visualizations that used the technology in a variety of ways, while reflecting the choreographic build. In this production, the mice were mainly used as spatial inputs to the projected visualizations, but we also incorporated other novel uses of the mice. For example, there were moments in the piece where the dancers would push a mouse button to trigger a fireworks visualization. There was also a movement phrase that involved two dancers lying on their backs, shaking the mice to change the transparency of a visualization.

The dancers’ movement vocabulary was restricted while holding the mice, but since they were able to control visualizations that extended beyond their own bodies, the mice augmented their expressiveness. For example, the fireworks visualizations was triggered by dancers’ finger movements. Unless seated in the first few rows, the audience would not typically be able to see subtle finger movements. Therefore, the fireworks visualizations made these subtle movements visible

Production	Num. of Choreographers	Num. of Dancers	Num. of Visual Artists	Num. of Technologists	Size of Audience	Show Length
A Mischief of <i>Mus musculus</i> (2008)	1	6	1	1	800	11 min
Whispering to Ophiuchus (2009)	1	7	1	2	1000	22 min
Bodies/Antibodies (2010)	1	4	*	3	150	11 min
An Instance Of... (2010)	1	3	*	3	965	3 min
The Angled Angels Assembly (2011)	2	7	*	3	100	14 min
Heavy Recursion (2011)	1	5	*	1	850	15 min

Table 1. Summary of the interactive dance productions described as case studies. *Denotes that technologists served as code artists.

to the audience in the form of a new expression. While *Augmented Expression* was not yet a design goal, it was clearly a side effect of the technology in this production.

The dance movements in this production were also choreographed to make the technology obvious to the audience to achieve the goal of *Connected Kinetics*. We approached this goal by incorporating exaggerated movements in which the dancers would swoop down with their arms to pick up the mice. The mice rested on illuminated vitrines when not in use, which highlighted their importance in the dance.

Dance 2: *Whispering to Ophiuchus*

“Whispering to Ophiuchus” was a large undertaking for our team, involving a choreographer, a choreographic assistant, two technologists, and one visual artist. This piece (Figure 2B) was 22 minutes long. Presenting this dance production as a case study is very interesting in that there were many disappointments in this production: the hardware was being developed during the production process (which lessened our ability to produce *Connected Kinetics*), and we inadvertently strayed from our design goal of *Aesthetic Harmony*. However, we had continued success with *Interactive Build*. More importantly, after our experience with this dance, we began reflecting on the principles of *Integrated Process* and *Augmented Expression* for future productions.

This dance was based on a narrative myth in which one dancer, having refused to participate in a ritual of sharing secrets, must be purified. The creative process involved the visual artist immersing himself in the choreographic development and creating visualizations that were based on the narrative. The visual artist had extensive meetings with the choreographer outside of rehearsals, where they collaboratively developed the narrative structure of the dance.

The technology in this piece was custom-built during the production cycle and was not completed in time to fully test prior to production week. During rehearsal, the dancers wore 3D accelerometers on each wrist with a wire running up the dancers’ arms and down their torsos to a battery-powered, wireless-transmitter pack at their sternum. Due to technological issues prior to the live performance, we opted to use logged motion data, captured during dance rehearsals, as input into the visualizations. The visualizations in this piece were heavy in imagery related to the narrative: changing constellations, an eclipsed moon, serpents, dark clouds, crumbling columns, and figures that represented the dancers’ ‘secrets.’ In contrast to “A Mischief of *Mus musculus*,” the visu-

alizations were detailed and figural to supplement the narrative. The design of these visualizations was so focused on the narrative sequence that we lost sight of *Aesthetic Harmony*.

Results from focus groups with both dancers and audience members indicated that there were moments in the dance where the visualizations overpowered or distracted the dancers. In the dancer focus group, one dancer said:

I caught myself looking at the screen a lot... I feel like it would take away, and that’s coming from a dancer standpoint... I know I was supposed to be [doing a specific movement], but there were some points where I found myself distracted by the screen.

Our audience focus group consisted of five participants that were experts in either performing arts or technology. The participants watched a video recording of this dance piece and four of the participants also saw the performance live at an earlier date. Participants agreed that there were too many visual aspects of the dance piece that were competing for their attention, stating that there were “many things to look at.” One participant described a balanced ebb and flow between attention to the visualizations and attention to the dance itself. While participants agreed that there were quiet moments in the visualizations and the dance movements, they reported that some of the interactive visualizations were jolting.

In team reflections, we discussed two disappointments with this piece. Our main regret was that our technology was not developed earlier in the production process. This made it difficult for implications of the technology to impact the interactive visualizations and choreography, which greatly diminished the *Connected Kinetics*. Also, since the visual artist was heavily involved in developing the narrative structure of the dance, he was primarily absorbed with developing visualizations representative of that narrative; thus interactivity and *Aesthetic Harmony* were less heavily considered.

Since the technology was not fully integrated, a new role emerged in this production, which is the role of a Video Jockey (VJ), who would use keyboard shortcuts to add additional content or change the responsiveness of the visualizations, if she felt that the aesthetics of the visualization could be improved. Therefore, the VJ’s primary purpose was to support *Connected Kinetics*, in the absence of responsive technology. During a solo in this piece, a dancer would often strike her staff upon the stage, and upon every strike, the VJ would press a key to trigger shooting stars. The rationale was to augment the interactive experience using keyboard-

controlled visualizations in the area where the technology was not used, preventing the breakdown of *Connected Kinetics* and also enhancing *Interactive Build* by helping the visualizations to be in line with the choreographic build.

The role of the VJ in this piece was filled by either the choreographer's assistant or a technologist, which required both of them to be skilled in making dynamic, real-time, aesthetic decisions using the provided visual controls. After having one of our technologists fill the VJ role, we later reflected on how having a technologist immerse himself in the choreographic process greatly improved the *Connected Kinetics*. It was at this point that we began exploring *Integrated Process* as a possible design principle for future dance production. The process of creating and using keyboard-controlled visualizations often lead to new considerations for how the technology could augment the choreography. Through this, we also began to see *Augmented Expression* as important.

Dance 3: Bodies/Antibodies

"Bodies/Antibodies" (Figure 2C) was a student-choreographed dance, performed at our institution. The dance simulated the labor force of the human body, antibodies, and what happens when an antibody is infected with a pathogen. While there was a narrative structure to this dance, it was more abstract than the narrative in "Whispering to Ophiuchus." Our team consisted of one choreographer and three technologists. This was our first piece without a visual artist, so the technologists filled in as code artists and regularly attended the dance rehearsals, allowing *Integrated Process* to emerge as a design principle. We also focused on *Aesthetic Harmony* and *Connected Kinetics*.

In this piece, we used two different technologies: the wireless gyroscopic mice used in "A Mischief of *Mus musculus*" and wireless, 3D accelerometers in small blue boxes. Instead of dancers holding the devices, both technologies were embedded into the dancers' costumes. Our software used data from both technologies as input into the interactive visualizations. This was the first dance production in which the technologists took a lead role in developing both the design and the interactivity of the visualizations. One technologist created a palette of interactive visualizations based on the theme of the dance: cell division, bacteria consumption, infection, and remedy. Another technologist incorporated the blue box data into the interactive visualizations. The third technologist used an *Integrated Process* to focus on how the visualizations could be controlled through *Connected Kinetics* and *Interactive Build*.

Based on our experience with "Whispering to Ophiuchus," we were cautious about the balance between visualizations and dancers as a way of achieving *Aesthetic Harmony*. In particular, we did not want our visualizations to overpower the dancers. We approached this goal by creating a match between what appeared on the cyclorama (the screen behind the dancers) and what was happening on the stage. For example, when two dancers were huddled together, the visualization was a single cell. When they separated, the single cell split into two cells. Each dancer's cell representation was present and visible but not flashy or distracting. The visualizations in

this piece reflected what was happening on the stage, rather than what was happening in the narrative. This relationship led us to understand the value of *Connected Kinetics*, as a quality of interactivity that emerged from mapping the stage to the cyclorama. Even when control of the visualizations was only loosely coupled, it was not the individual visualizations but the temporal relationship between the dancers and visualizations that pushed the audience to believe that a union between dance and technology had occurred.

One example of *Interactive Build* is the cyclical conclusion of the choreography. The dance started with two dancers, progressed to five dancers, resolved to four "living" dancers, and ultimately concluded with two dancers repeating the movements from the opening scene. The visuals followed a similar build, accounting for the number of "living" dancers, and having the same visuals for the opening and closing scenes.

The dance focus group, the dancers in this piece indicated that they were very pleased with the visualizations. One dancer said that the visualizations "really helped the organic feeling of the piece." Two other dancers brought up the issue of balance: "Just thinking in comparison of the work from last year, I felt these visuals really complemented the dance better." Similarly, another dancer said, "I didn't feel like we were competing... like the technology was competing with the dancers... whereas it could have seemed like that before."

The introduction of a technologist into the choreographic process encouraged the dancers to become more involved in the integration of choreography and technology. Dancers asked more questions about the technology and their control over the interactive visualizations. In one section, the technologist timed a visualization of a cell splitting with a related movement phrase. Originally, the connection between movement and visualizations was achieved by the technologist timing her key-press to the movement phrase. However, a dancer noticed that it would be easier if the dancers took their cue from the visualization, waiting until they saw the cell division before starting their dance sequence. Therefore, the *Integrated Process* in this dance extended how the dance could inform the technology and how the technology could inform the dance. From the dancer focus group, it was clear that the dancers appreciated the *Integrated Process*, but that it could be explored further. One dancer said that it would be interesting for the choreographer and technologist to collaborate more, to each inspire the other in case of creative blockage.

Dance 4: An Instance Of...

"An Instance Of..." (Figure 2D) was largely developed during a dance-technology workshop. In this piece, *Augmented Expression* was an explicit goal while the notions of *Aesthetic Harmony* and *Integrated Process* evolved.

This piece was primarily developed by one choreographer and three technologists. However, since it was created during a workshop that involved dancer participation, the three dancers in this piece contributed significantly to the development of the choreography. The technologies used were the blue boxes from "Bodies/Antibodies" and theater microphones worn on the dancers' heads. This was our first dance

with sound input to control visualizations. Each of the three dancers controlled a uniquely shaded palette of ribbons, created through their body sounds of clapping, smacking, stomping, or heavy breathing. The color palette switched based on the highest level of activity detected from the blue boxes. The dancers listened to the musical score through ear buds connected to their synchronized iPods. However, the music was not played for the audience. Instead, the audience saw the music's audio scope on the cyclorama and could only hear the sounds of the body captured through the theater microphones. Since the technology provided a new method of *Augmented Expression* through sound rendering, the choreographer felt comfortable using a sound-intensive, music-excluding style.

Since this was our fourth interactive dance piece, certain design goals were accomplished instinctively. For example, we successfully achieved *Connected Kinetics* by having exaggerated movements and sounds to allow audience members to see the relationship between sounds and the visualizations. The visualizations were continuously variable and responsive [19]. However, *Interactive Build* was not something that we designed for, as the variability in our visualizations was appropriately engaging for a three-minute dance.

In this piece, the visualizations enlarged with the noise intensity, fading over time. In the focus group, the dancers indicated that they were pleased with the visualizations, seeing themselves as the “main event” and the ribbons as peripheral to the audience's attention. One dancer felt cohesion between the visualizations and the dance and described it as an “overall image, rather than individual things.” However, another dancer reported that the visualizations were “too toned down” and compared to our previous dances, on the “other end of the spectrum.” Based on this feedback and team reflections, we realized that an equal balance between the visualizations and the dancers was not a rule for *Aesthetic Harmony*, as even the movement among each of the dancers was not always equally balanced. Rather, the focus should be on how each of the pieces form the whole, to convey the choreographer's intent.

The workshop format improved our *Integrated Process* by helping the technologists, choreographers, and dancers to feel more comfortable interacting with each other, both in the choreographic development and in the integration of dance movements with technology. We tested several variations of sound interaction and visualizations, asking the dancers to perform solos with each variation. This process allowed us to see which visualizations were most engaging.

Dance 5: *The Angled Angels Assembly*

“The Angled Angels Assembly” (Figure 2E) successfully built on the design accomplishments from “An Instance Of...”, incorporating *Aesthetic Harmony*, *Augmented Expression*, *Interactive Build*, and *Connected Kinetics* as design principles. *Integrated Process* happened implicitly in this piece, which aimed to investigate the boundaries between the virtual world and the physical world.

The development team for this piece included two choreographers and three technologists. One of the technologists developed a palette of visualizations before the choreographic de-

velopment process began. Then, the other two technologists were involved in the goals of *Connected Kinetics* and *Interactive Build*. The technology consisted of an overhead camera, mounted in the rafters above center stage, and custom software using background subtraction and a k-means clustering algorithm to track the dancers in space and time.

The *Integrated Process* between technologists and choreographers happened implicitly, as a result of the rehearsal schedule. There were two rehearsals each week with one rehearsal dedicated to developing choreography and the other dedicated to the integration of choreography and technology. This involved both changing the technology to work with the choreography and changing the choreography to work with the technology, while also making refinements to the movement.

To reflect the concept of boundaries, the visualizations in this piece made heavy use of straight and joined black lines that moved in relation to the position of the dancers. For *Connected Kinetics*, we wanted to ensure that the two-dimensional relationship between dancers and visual components was well understood, and we did this by using *Interactive Build* to establish a kinetic relationship with the visualizations, moving from very simple to more complex mappings. For example, the opening section had one dancer enter from stage right with a line segment drawn above her head. This line expanded horizontally from the side of the cyclorama to the dancer's current position. The line moved and stopped in accordance with the dancer, and then another dancer was added to the stage who would control a new line segment that moved vertically. Eventually, all the dancers would come on stage, each controlling their own line. The build continued by changing the lines to linear angles, introducing color, introducing a filtered video feed from the camera, and eventually introducing colored blocks to form a Mondrian-themed visualization of overlapping boundaries.

Until this performance, our approach to *Aesthetic Harmony* was largely concerned with ensuring that the visualizations did not overpower the dancers, attempting to achieve an equal balance of attention between the visualizations and the dancers. However, after “An Instance Of...”, we realized that an equal balance was not always appropriate. This production was the first time that we intentionally moved away from that equal balance for segments of the dance.

Dance 6: *Heavy Recursion*

A more recent production, “Heavy Recursion,” (Figure 2F) was a successful case study in which we explicitly incorporated all five design principles. The technologies used in this piece included an overhead camera and a theater microphone to capture sounds from the dancers and props. The intent of the dance was to explore the impact that technology has on socio-human experiences. The choreography was influenced by circuit boards, programming code, technology failures, and the demands of our devices. The visualizations consisted of filtered, overhead video feeds of the stage, lingering silhouettes of the dancers, enclosed spaces, complex grid and wire growths, and renderings of human and machine noises. Since the dance incorporated different uses of the

overhead camera and sound input, foreshadowing and overlay techniques became part of the *Interactive Build*. For example, we introduced the sound rendering visualizations for a few moments at the start of the performance, so the audience would be primed for later sections when they were used heavily, thus achieving *Connected Kinetics*. The use of filtered video greatly enriched the *Connected Kinetics*. The relationship between dancer kinetics and visual kinetics was directly represented, allowing the audience to experience the dancers' movements from an additional, top-down, perspective.

The *Integrated Process* began early in the production cycle with prototype visualizations projected behind the dancers in early rehearsals. As the dancers and choreographer experimented with their movement vocabulary in the rehearsal space, they could see themselves projected on the cyclorama. Sometimes the choreographer would have the dancers look at themselves on the cyclorama while performing specific movement phrases. During these times of exploration, the choreographer and technologist discussed ideas for new visualizations or new uses of the technology. This sometimes involved the technologist changing the visualizations to see how they responded to the dancers' control with different parameters. Like "Whispering to Ophiuchus", the choreographer and visualization developer spent a lot of time outside of the rehearsal space discussing the structure of the dance and the role of the visualizations. The coupling was so tight between visualizations and the dance that certain sections of the dance could not be set until the choreographer and technologist finalized the interaction. In their focus group, the dancers celebrated the collaborative effort between the choreographer and technologist, and enthusiastically discussed how the technologist had an influential role in the creative process.

Although [the technologist] is not a dancer, he has been working on the project long enough that he's starting to see what we're doing and getting a feel for it. He definitely had moments where he was like 'Well, what if you did this?' And he was talking about the dancing!

Similar to "The Angled Angels Assembly," there was a focus on *Aesthetic Harmony* between the visualizations and the dancers, but the aim was not an equal balance. Rather, there was a deliberate decision to showcase the visualizations and the use of technology. In one section, attention was drawn to dots that expanded and splattered, which was clearly a rendering of the voices of the dancers. In another section, the video-filtered visualizations gave audience members an overhead view of just the dancers, drawing attention away from the dancers on stage to their images on the cyclorama. During the dancer focus group, the dancers made no mention of feeling 'overpowered' by the visualizations. Instead, they discussed how they felt complimented by them.

The dancers reported that they felt the closest connection to those visualizations that were the most responsive to them personally. For example, the dancers who 'spoke code' during the dance felt a close connection with the visual renderings of their voices. The dancers explained that the reason their connection was the closest to these visualizations was because these visualizations provided a different way

for the audience to connect with them and experience their movements; demonstrating adherence to the principle of *Augmented Expression*. One dancer said:

When I would cough, I could see the cough. I was like, 'Oh my gosh! That noise I did, just left that mark on the screen!' [...] Even when you're not dancing, there's still something there on the screen that you can leave behind.

Allowing the audience to view the dance from an additional top-down perspective is clearly a form of *Augmented Expression*. This different perspective allowed dancers to have their backs to the audience for extended periods and do prolonged segments of floor-work, which typically make the dancers hard to see. The new mediums of expression were not only experienced by the audience, but the dancers as well. The dancers were given opportunities to watch the visualizations as they interacted with them. This helped them to appreciate the visualizations on a deeper level, as they had been dancing with them for the entire production process.

DISCUSSION

Principles in Practice

Principles such as *Aesthetic Harmony* can seem obvious at first, especially to designers in fields where harmony is a basic principle [8]. While it may seem relatively straightforward to design visualizations and choreography to achieve *Aesthetic Harmony* in interactive dance, there are many challenges in practice. Many interactive visualizations are first created and viewed on a laptop or desktop computer. When these visualizations are projected on a large cyclorama, with or without theater lighting, perceived characteristics such as size, emphasis, colors and intensity change drastically, requiring additional refinements to the visualizations.

Another difficulty in achieving *Aesthetic Harmony* stems from the differences in audience perspective which vary based on where any particular audience member sits. If an audience member sits farther back and therefore higher up in the theater, the bottom of the cyclorama is above the dancers' heads, giving the audience a non-occluded perspective of the visualizations. If an audience member sits closer to the stage, they have a lower perspective and the cyclorama is right behind the dancers, giving the audience a layered view of the dancers in front of the visualizations. This issue obviously varies with different theater layouts, but most theaters will necessitate this consideration. As we've previously reported, time constraints mean that there is often very little that can be changed choreographically or technologically once a dance moves into the performance space [10]. Visualizing these audience viewpoints earlier in the process, before moving to the stage, is the best approach, though quite difficult.

Connected Kinetics might also seem like obvious principle, but it is challenging in practice. Visualizations were designed on a laptop and a finger on a touchpad cannot accurately simulate various sensing technologies. We have attempted using logged data and video for testing outside of the studio, but because each dance piece involved a different number of dancers and movement vocabulary, these logs were of limited

use. When using a camera-tracking system, moving from the rehearsal space to the stage space changed the interaction. A difference in stage size could mean that dancers are closer or farther apart, reducing tracking consistency and accuracy. Costumes, scenic elements, and props are introduced late in the process and can also degrade or change the tracking. These challenges reduce the responsiveness and predictability of the interaction, reducing *Connected Kinetics*.

Bidirectional Effects

The design principle of *Augmented Expression* is about ensuring that the use of technology adds to the choreographic and physical expressiveness that characterizes dance. What is interesting about this principle is that it can be considered a bidirectional principle. While the technology should augment the expressiveness of the dancers, the technology should also be augmented *by* the dancers. We see this in many of the interactive visualizations that we have created, where the effects achieved could not have been achieved in any other way, other than sensing dancers' movements in real-time.

Our title, "Dance-Inspired Technology, Technology-Inspired Dance" reflects the increasingly integrated production process which has been one of our greatest successes as a team. When the *Integrated Process* is working well, the inspiration is bidirectional: the choreography inspires the development of novel and relevant interactive visualizations and the interactive visualizations inspire the development of novel choreography. In addition, a multi-disciplinary team working together over the long term can lead to entire dances that are technology-inspired, such as "Heavy Recursion."

Breaking The Rules

The principles we have presented are not fundamental laws of design. We acknowledge that in some contexts, breaking the rules can be a necessary part of artistic exploration. Merce Cunningham was well known for his innovative work with technology, much of which broke the rules of traditional choreography [5]. In our work, we have at times purposely broken our own design principles. Four of the six presented dances had at least one section where the visualizations did not have *Connected Kinetics*, moving in a pre-programmed fashion with clearly no influence from the dancers. For example, in one section of "The Angled Angels Assembly," a cross section of lines moved slowly and predictably across the cyclorama, so attention could be drawn away from the visualizations and toward the dancers. What we found was that even when the visualizations were not dancer-controlled, a lack of responsiveness could convey meaning or intent, which is similar to what Snibbe found [19].

Principles in Context

Within academic dance settings, choreography is typically set on, and often designed for, student dancers, who do not have the same skill level as professional dancers. This means that there is less focus (if any) on improvisational dance. While Coniglio recommends improvisation in interactive dance [2], this does not work well in academic dance. In our case studies, we observed that choreographers used improvisation as

tools for working out elements within a dance, but the improvisation was mainly used in the rehearsal process for choreographic development. This approach allowed the dancers to play with the technology and experience it at its limits, while minimizing the risk of degrading the public performances with less skilled dance. This is an example of how the situated context of academic dance has informed the development of our design principles. Our principles of *Connected Kinetics* and *Augmented Expression* can both be enhanced through the use of improvisational dance, but we don't consider improvisation in the final performance a requirement to be in line with these principles. We expect that the academic setting contextualizes similarly across other performing arts such as music and theater, where significant public improvisation is mainly done at the professional level.

The majority of our dance productions have been formal concert dance pieces. The formality of this venue defines a set of constraints on what is considered acceptable and also sets a frame of reference for the critique and evaluation of a piece. Constraints of formal dance include the following:

- Performers don't usually acknowledge the audience.
- Highly experimental dance methods are discouraged.
- The performance stays on the stage and does not spill over into audience space.
- A high level of skill, practice and refined performance is expected by the audience and the choreographer.
- The performance is expected to be nearly the same from night to night.
- Technologists and other production support personnel are not supposed to be seen as part of the performance.

Because of these constraints, more experimental methods which could lead to mistakes or where the outcome is unknown are not available to the designers of formal productions. This framing of expectations can be a source of tension when technology is introduced, as the level of variation in how technology responds to the dancers may be uncomfortable for the choreographers. In some of our productions, we have added computational controls to account for and minimize errors due to noise or drift in sensing technologies, as a way to minimize the unpredictability of interactive technologies between performances. This design tension is interesting when considering how the dancers and choreographers value the uniqueness of each performance. In our project we have witnessed the choreographers adapt and even embrace the variability in technological response. One of our choreographers commented "In some ways that is what makes this so fun, because you never know exactly what the visualizations will look like during the performance: each night is a bit different." However, the formal concert constraints still set a limit on how much variability is considered acceptable. This can limit the ability to have intense *Interactive Build*. In two of our less formal performances, we were able to break out of these constraints and make use of more improvisation, less error control, and allow some explicit interaction with the audiences. A less formal dance performance setting changes the *Integrated Process*, allowing technologists to become an acceptable and visible part of the production.

CONCLUSIONS

We have presented five design principles to help technologists succeed when integrating technology into dance: *Connected Kinetics*, *Augmented Expression*, *Aesthetic Harmony*, *Interactive Build*, and *Integrated Process*. These design principles emerged from and contributed to the six dance productions that were created through this practice-based research. These case studies illustrate a variety of processes, team composition and dance production attributes, demonstrating that these design principles have been tested in a variety of situations. The design space for interactive dance is large and multi-dimensional [11], but these design principles will be important considerations regardless of where a particular production fits within that design space.

We have discerned design principles that are within the scope of interactive dance. However, as we have built upon the design principles offered by Snibbe for interactive art installations [19], researchers in related domains may be able to build upon the design principles we offer. In particular, the domains of theater and music performance have temporal constraints and audience relations similar to formal concert dance. Thus, practitioners wishing to integrate technology into those domains are likely to be able to build off of our principles.

ACKNOWLEDGEMENTS

This work was funded by the NSF CreativeIT (#IIS-0855882). We thank our reviewers for their valuable feedback, the dancers, the choreographers, Danielle Lottridge, and other collaborators who have participated in Dance.Draw.

REFERENCES

1. Carroll, E. A., Lottridge, D., Latulipe, C., Singh, V., and Word, M. Bodies in critique: a technological intervention in the dance production process. In *Proceedings of the ACM 2012 Conference on Computer Supported Cooperative Work, CSCW '12*, ACM (New York, NY, USA, 2012), 705–714.
2. Coniglio, M. The importance of being interactive: New visions in performance. *The Impact of New Technologies* (2004), 5–12.
3. Corness, G., Carlson, K., and Schiphorst, T. Audience empathy: a phenomenological method for mediated performance. In *Proceedings of ACM Creativity & Cognition 2011* (2011), 127–136.
4. deSpain, K. Dance and technology: A pas de deux for post-humans. *Dance Research Journal* 1, 2-17 (2000).
5. Farley, K. Digital dance theatre: The marriage of computers, choreography and techno/human reactivity. *Body, Space and Technology* 3, 1 (2002), 39–46.
6. Faver, C. Toward a digital stage architecture. *Artful Media* (2001), 6–9.
7. Hook, J., Green, D., McCarthy, J., Taylor, S., Wright, P., and Olivier, P. A VJ centered exploration of expressive interaction. In *Proceedings of ACM CHI 2011* (2011), 1265–1274.
8. Krause, J. *Design Basics Index*. How, 2004.
9. Latulipe, C., Carroll, E. A., and Lottridge, D. Evaluating Longitudinal Projects Combining Technology with Temporal Arts. In *Proceedings of ACM CHI '11*, ACM Press (May 2011), 1835–1844.
10. Latulipe, C., Wilson, D., Huskey, S., Gonzalez, B., and Word, M. Temporal Integration of Interactive Technology in Dance: Creative Process Impacts. In *Proceedings of the 8th ACM conference on Creativity and Cognition*, ACM (2011), 107–116.
11. Latulipe, C., Wilson, D., Huskey, S., Word, M., Carroll, A., Carroll, E., Gonzalez, B., Singh, V., Wirth, M., and Lottridge, D. Exploring the design space in technology-augmented dance. In *ACM CHI Extended Abstracts 2010*, ACM (2010).
12. Loke, L., and Robertson, T. Studies of dancers: Moving from experience to interaction design. *International Journal of Design* 4, 2 (2010).
13. Mandilian, L. E., Diefenbach, P., and Kim, Y. Information overload: a collaborative dance performance. In *Proceedings of the 1st ACM International Workshop on Semantic Ambient Media Experiences* (2008), 57–60.
14. Maynes-Aminzade, D., Pausch, R., and Seitz, S. Techniques for interactive audience participation. In *Proceedings of ICMI '02*, IEEE Computer Society (2002), 15–.
15. Meador, W. S., Rogers, T. J., O'Neal, K., Kurt, E., and Cunningham, C. Mixing dance realities: collaborative development of live-motion capture in a performing arts environment. *Comput. Entertain.* 2 (2004).
16. Reason, M., and Reynolds, D. Kinesthesia, empathy, and related pleasures: An inquiry into audience experiences of watching dance. *Dance Research Journal* (2010), 49–75.
17. Reeves, S., Sherwood, S., and Brown, B. Designing for crowds. In *Proceedings of NordiCHI '10*, ACM (New York, NY, 2010), 393–402.
18. Sheppard, R., Kamali, M., Rivas, R., Tamai, M., Yang, Z., Wu, W., and Nahrstedt, K. Advancing interactive collaborative mediums through tele-immersive dance (TED): a symbiotic creativity and design environment for art and computer science. In *Proceeding of ACM MM'08* (2008), 579–588.
19. Snibbe, S. S., and Raffle, H. S. Social Immersive Media. In *Proceedings of ACM CHI 2009* (2009).
20. Suchman, L. A. *Human-Machine Reconfigurations. Plans and Situated Actions*, 2nd edition. Cambridge University Press, 2007.
21. Vogel, D., and Balakrishnan, R. Interactive public ambient displays: transitioning from implicit to explicit, public to personal, interaction with multiple users. In *Proceedings of ACM UIST'04* (2004), 137–146.