Capturing traces of the dance learning process

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Abstract

This thesis focuses on designing interactive tools to understand and support dance learning from videos. Dancers' learning practice represents a rich source of information for researchers interested in designing systems that support motor learning. Indeed, dancers embody a wide range of skills that they reuse during new dance sequences learning. However, these skills are in part the result of embodied implicit knowledge.

In this thesis, I argue that we can capture and save traces of dancers' embodied knowledge and use them to design interactive tools that support dance learning. My approach is to study real-life dance learning tasks in individual and collaborative settings.

I first conducted interviews with expert dancers to understand how they learn new dance movements. I identified a set of learning techniques that dancers use while learning. Based on the findings, I conducted a field study with contemporary dancers. I asked them to learn a dance sequence from a video and report on their learning process using documentation materials. I highlighted how dancers structure their learning process by segmenting the choreography. This study led me to design a learning-support tool called *MoveOn* that captures, reveals, and supports dancers' segmentation strategies. *MoveOn* lets dancers decompose video into short, repeatable clips and save a trace of the segmentation process over time. This trace served as an effective analysis tool for identifying the changes in focus and understanding dancers' segmentation and recomposition processes. Then, I explore the possibility of reusing dancers' segmentation to teach dance. I showed that dancers and teachers produce different segmentations but use similar strategies to decompose and recompose segments. I suggest that a teacher-created segmentation can be shared to teach dance to novice dancers. Following these studies that focus on the individual dancer, I looked at dance learning in collaborative settings. I conducted a 12-month longitudinal-study with a dance company that was learning an existing contemporary dance piece. I examined how dancers collaborated and shared their knowledge through digital and physical artifacts, including *MoveOn*. The findings showed that artifacts represent dancers' knowledge in different forms depending on the expertise, the vocabulary, and the viewpoint of their creator, which encompasses dancers' learning preferences. Dancers use artifacts to isolate, analyze, and focus on different aspects of the choreography and distribute the same information

to all participants.

Based on the findings from all these studies, I discuss the challenge of capturing embodied knowledge to support dancers' learning practice. My thesis highlights that although dancers' learning processes are diverse, similar strategies emerge to structure their learning process.

Résumé

Cette thèse porte sur la conception d'outils interactifs pour comprendre et faciliter l'apprentissage de la danse à partir de vidéos. Les processus d'apprentissage des danseurs représentent une source d'informations riches pour les chercheurs qui s'intéressent à la conception de systèmes soutenant l'apprentissage moteur. En effet, les danseurs experts réutilisent un large éventail de compétences qu'ils ont appris. Cependant, ces compétences sont en partie le résultat de connaissances implicites et incarnées, qui sont difficilement exprimables et verbalisables par un individu.

Dans cette thèse, je soutiens que nous pouvons capturer et sauvegarder une trace des connaissances implicites des danseurs et les utiliser pour concevoir des outils interactifs qui soutiennent l'apprentissage de la danse. Mon approche consiste à étudier différentes sessions d'apprentissage de danse dans des contextes réels, aussi bien individuels que collaboratifs.

Dans un premier temps, j'ai mené des entretiens avec des danseurs experts pour comprendre leur apprentissage de nouveaux mouvements de danse. Cela m'a permis d'identifier un ensemble de techniques d'apprentissage utilisés par les danseurs lors de leur apprentissage. Sur la base de ces résultats, j'ai mené une étude de terrain auprès de danseurs contemporains. Dans cette étude, des danseurs contemporains ont appris une séquence de danse à partir d'une vidéo et ont réalisé un compte-rendu de leur processus d'apprentissage en utilisant du matériel de documentation. Cette trace papier a mis en évidence la façon dont les danseurs structurent leur apprentissage en segmentant la vidéo de danse. Cette étude m'a conduit à concevoir un outil de soutien à l'apprentissage appelé *MoveOn* qui capture, révèle et soutient la stratégie de segmentation des danseurs. *MoveOn* permet aux danseurs de décomposer une vidéo en clips courts et répétables ainsi que de sauvegarder une trace de ce processus de segmentation. *MoveOn* se révèle être un outil d'analyse efficace pour identifier les changements de foci des danseurs et permetre de comprendre leurs processus de segmentation et de recomposition. Je me suis ensuite intéressé à la possibilité de réutiliser ces traces de segmentation pour en faire un outil pédagogique permettant d'enseigner le mouvement de danse. Au travers une observation structurée, j'ai étudié comment une segmentation créée par un professeur de danse pouvait être partagée pour enseigner la danse à des danseurs novices. Cela m'a

permis de décrire comment les danseurs et les enseignants produisent des segmentations différentes mais utilisent des stratégies similaires pour décomposer et recomposer des segments vidéos.

À la suite de ces études se concentrant sur l'apprentissage du mouvement de façon individuel, j'examine l'apprentissage de la danse dans un cadre collectif. J'ai mené une étude longitudinale de 12 mois avec une compagnie de danse travaillant sur la mise en scène d'une pièce de danse contemporaine existante. Dans ce cadre, j'examine comment plusieurs acteurs (danseurs, professeurs, directeurs de compagnie) collaborent et partagent leurs connaissances du mouvement par le biais d'artefacts physiques et numériques, dont *MoveOn*. Les résultats montrent que les artefacts créés par les participants représentent leur connaissance sous différentes formes dépendant de leur expertise, leur vocabulaire et leur point de vue. Les danseurs et les professeurs utilisent des artefacts pour isoler, analyser, et se concentrer sur différents aspects de la chorégraphie ainsi que pour distribuer les mêmes informations à chacun. Finalement, je montre que ces artefacts englobent les préférences d'apprentissage de chaque acteur du projet et je dresse un tableau de tous les artefacts utilisés.

Sur la base de ces résultats, je contribue à une meilleure compréhension des processus implicites qui sous-tendent l'apprentissage de la danse dans des contextes individuels et collectifs. Je présente plusieurs stratégies d'apprentissage utilisées par des danseurs et j'affirme que l'on peut documenter ces stratégies en sauvegardant une trace de l'apprentissage. Je discute de l'opportunité que représente la capture de ces connaissances incarnées et j'apporte de nouvelles perspectives pour la conception d'outils d'aide à l'apprentissage du mouvement par la vidéo.

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Introduction

To reach expert level, dancers train to acquire complex movements and phrases efficiently, they develop techniques and patterns that they repeat when learning a new choreography. I argue that capturing and understanding these techniques and patterns can foster the design of interactive tools to support dance learning. However, these techniques are deeply embodied by dancers, automatic and unconscious to the learner. I explore how to capture traces of embodied dance learning processes to design interactive tools to support and understand dance learning.

Dance involves both artistic and aesthetic expression and encompasses some of the richest movement skills that humans can achieve [Bläsing et al., 2010]. Expert dancers, through experience, report that they develop and accumulate a set of movement habits and knowledge, a "baggage" of movement [Purser, 2018]. For example, one of the skills that expert ballet dancers learn and use in their daily practice is being *en pointe* (Fig.1.1). This technique requires proper foot positioning, balance, and alignment of the legs and torso [Russell, 2015]. If you ask professional dancers to teach you how they rise onto their point shoes, they will probably perform in front of you, they may give you advice or metaphor, but they are unlikely to explain it only with words.

Figure 1.1: Rising onto point shoes is an example of knowledge embodied by experts ballet dancers.

Expert dancers know how to position their body for doing a *pointe*, but they cannot easily put words on it. Tanaka [2013] argues that such motor skills are a certain type of knowledge *embodied* into dancers' body. Tanaka called it *embodied knowledge*. Kirsh et al. [2009] argues that such knowledge cannot be made directly conscious and cannot be articulated easily with words. For example, expert dancers do not need to

verbalize or represent in their minds the procedures required to be *en pointe*. Embodied knowledge regroups motor skills and techniques that people use but cannot explain [Chugh et al., 2015]. In the case of dance, the type of knowledge that dancers embody is strongly influenced by the dance style and the context [Dillenbourg, 1999]. Throughout my thesis, I focused on contemporary dance, a form of dance that incorporates elements from many dance styles, mixing codified techniques with improvisation elements.

I am interested in using embodied knowledge as an input for the design of interactive tools supporting the dance learning process. Embodied knowledge, felt experience, and sensations have been the center of HCI researcher's attention to design body-based systems [Fdili Alaoui et al., 2017, Höök, 2018]. It inspired technologies for both dance performance [Eriksson et al., 2019] and dance education [Fdili Alaoui et al., 2012].

However, one of the challenges is how to access and capture embodied knowledge [Fdili Alaoui et al., 2015b, Höök et al., 2016]. Although embodied knowledge is difficult to verbalize, it can be captured through non-verbal forms of communication, such as performance, illustrations, gestures. HCI researchers used technology to make users reflect on their embodied knowledge and experience [Françoise et al., 2017, Ståhl et al., 2016, Cuykendall et al., 2015, Wilde et al., 2011]. This approach led to two complementary research questions: How can we capture and understand dancers' embodied knowledge as they learn new dance movements? and; 2) How can we apply the concept of embodied knowledge to the design of tools that support dance learning? My approach to understanding dancers' embodied knowledge is to capture traces of their learning process with interactive technology. Dancers might be reluctant to use new interactive technology [Calvert et al., 2005]. In order not to impose new technologies that dancers do not use or need, I focus on video, a medium highly present in dance studios [Sööt and Viskus, 2013]. I designed a technology that allows dancers to manipulate video with the goal to learn dance. Our technology keeps a trace of their manipulation, which allows us to study their learning practice and embodied knowledge. I started my research journey by studying the context of individual dance learning, and then broadened the scope of my research to encompass collective dance learning.

1.1 Thesis Statement

I argue that by understanding some of the underlying mechanisms appearing during learning, we can design interactive tools leveraging these mechanisms to support dancers' learning. In turn these tools can help us better understand embodied mechanisms in both individual and collaborative learning by capturing traces of the learning process. In individual dance learning, I studied how dancers learn dance from video and explored how they segment dance video during learning. I argue that this segmentation process is an implicit process embedded in dancers' learning practices. I designed *MoveOn*, a video-based technology that supports the process of segmenting videos. *MoveOn* captures a trace of video segmentation over time and makes it interactive, allowing us to better understand this phenomenon. In collaborative dance learning, I studied how artifacts embody dancers' knowledge and proposed implications for the design of interactive tools in this context.

1.2 Research methods

Dancers continuously adapt their movement to the environment and use their bodies to think, learn, and transmit their knowledge [Delahunta and Zuniga Shaw, 2006, Delahunta and Shaw, 2008]. Dance learning, whether alone or in a group, is grounded in a social and cultural context and understanding dance learning requires conducting studies in the field. I employed user-centered methods to observe and study dancers in real dance learning tasks and design an interactive technology based on my observation and studies. All these methods triangulate between observation, theory, and design of software, following the framework of Mackay and Fayard [1997] for human-computer interaction (HCI) research. Figure.1.2 summarizes the different steps of my research, balancing between the observation of dancers in the dance studio, the design of *MoveOn*- a technology probe that supports video segmentation - and theories coming from HCI, cognitive science, and dance literature. More specifically, I conducted an interview study, two participatory workshops, a structured observation, and a longitudinal observation study that I describe in the next section.

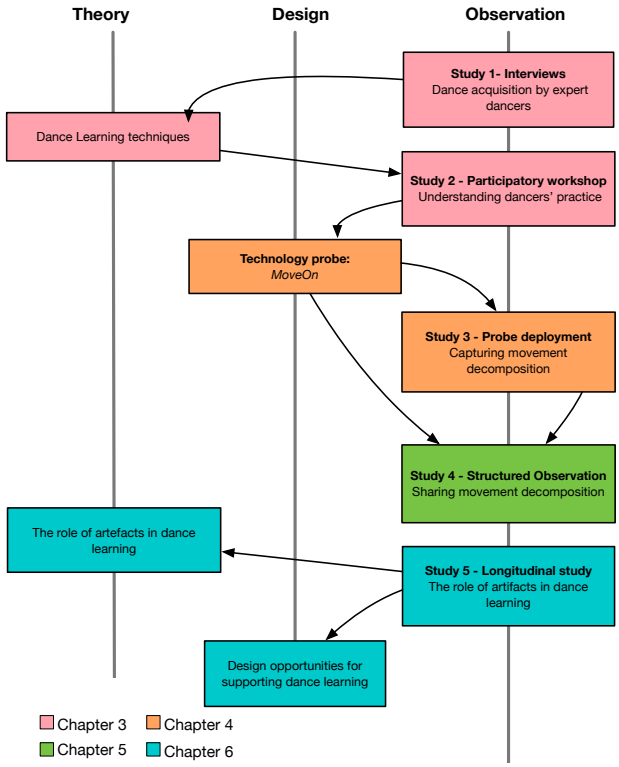


Figure 1.2. Method triangulation in this thesis. This research work mix qualitative methods such as structured observations of contemporary dancers in the dance studio, with the design and the evolution of *MoveOn*, a technology probe for supporting and understanding dance learning. All the "bricks" are connected with a common theoretical foundation from HCI, dance, and cognitive science domains.

1.2.1 Semi-structured interviews

Semi-structured interviews are a particular form of interview study where an interviewer explores a set of pre-defined themes with the interviewee. During the interviews, I used the critical object interview techniques described by Mackay [2002]. This technique is a variation of the Flanagan's Critical Incident Technique [Flanagan, 1954], which allows an interviewee to recall and reflect on past experiences. For each interview, I focused on gathering the dancers' perspectives on their learning process. I invited expert contemporary dancers to recall the last time they learned a new dance movement and ask them to describe it step by step. During these interviews, I sought to retrieve specific examples of how dancers learn movements and avoid generic answers.

1.2.2 Technology Probe

A technology probe is a simple, flexible, and adaptable technology usually deployed in a real-world situation. Hutchinson et al. [2003] argue that "*a technology probe has a social goal of collecting information about the use of the technology and the users; an engineering goal of field-testing the technology; and a design goal of inspiring both the users and the researchers about new technologies*".

I developed a technology probe [Hutchinson et al., 2003] and observed how dancers and teachers use it in dance studios. *MoveOn* is a multi-platform tool for segmenting dance videos into interactive segments. At first, I used this system to understand how dancers segment movement when learning a dance choreography. In a second study, I used the probe to produce a teacher-segmentation and I compared teacher's and dancers' segmentation strategies and how dancers learn on their own compared with the teacher segmentation. Finally, the probe was further developed to become a real system used by a dance company during a real re-staging of a contemporary dance choreography that lasted several months. This shows the versatility of *MoveOn* and its use in different contexts and methods.

1.2.3 Participatory workshop

A participatory workshop is an approach aimed at involving users in a task - a dance learning task in our case - and observing them as they perform that task. It offers the possibility of observing a task while adding an external element to this task, such as a technological tool. I conducted two participatory workshops with contemporary dancers. The first followed four dancers learning a dance choreography from a video and reporting on this process. The second study followed six dancers learning the same dance choreography but with *MoveOn*.

1.2.4 Structured observation

A structured observation [Mackay, 2014] is a form of quasi-experiment [Cook et al., 1979] where a researcher takes advantage of experiment design principles to compare qualitative data in a systematic way. A structured observation aims to compare two tasks and gather observational data to increase understanding of a problem. In a structured observation, researchers do not try to assess a hypothesis or test a new theory. Rather, they seek to generate new theories and insight into a problem. It allows researchers to explore promising issues, enhance the discovery of new ideas, generate design implications, and gain insight into the use of technology in real-world settings. I used a structured observation to compare two learning tasks mediated by *MoveOn*. In the first task, dancers learned on their own with *MoveOn*, while in the second task, dancers were required to follow a pre-defined segmentation created by their teacher.

1.2.5 Longitudinal study

A longitudinal study is a study conducted over a long period of time to observe and record what people do and how this changes over time. I

ran a longitudinal field study over eight months with a dance company in the process of re-staging an existing contemporary dance piece. I observed how dancers collaborate while learning a professional dance piece.

I studied dancers' collaboration through the lens of artifacts. Artifacts are lasting, durable, and public objects. Artifacts mediate collaborative learning [Sawyer, 2005] and provide concrete evidence of knowledge building and interactions within a group [Stahl et al., 2014, Stahl, 2013]. I used a longitudinal study because artifacts dynamically evolve over time which require to consider artifact over a long period [Bødker and Klokmose, 2012]

1.3 Contributions

In this section, I present and discuss the empirical, technological, and methodological contributions developed in the dissertation.

1.3.1 Empirical contributions

From an empirical point of view, I conducted five qualitative studies to understand dance learning practice in different contexts.

- I show that contemporary dancers engage in a set of highly varied strategies to learn dance phrases: segmentation, imitation, repetition, adaptation, mental simulation, and marking movements.

- I show that contemporary dancers engage in a segmentation process when learning from video. Although the segmentation process is an idiosyncratic practice, dancers and teachers adopt similar segmentation strategies.

- I show that the notion of video segmentation can be used to help novice dancers in learning dance from a video.

- I show that contemporary dancers produce and share a set of physical and digital artifacts during the collaborative learning of *Frame(d)*. They use artifacts to segment the choreography into simpler components, analyze the choreography, reduce the learning task's difficulty, and solve specific problems collectively.

1.3.2 Technological contributions

- I developed a technology called *MoveOn* that lets dancers segment dance videos and saves their segments into a segment history. *MoveOn* serves as an effective analysis tool to identify the changes in focus and understand segmentation and recomposition patterns.

1.3.3 Methodological contribution

- I contribute a way to capture traces of user's segmentation process. This allow us to trace and better understand dancers learning practice.

- The combination of methods used leads to an ecologically valid perspective of dance learning in individual and group contexts.

1.3.4 Design contribution

- I contribute to illustrate how reification of user's actions support the design of tools for dance learning.

1.4 Thesis Overview

Chapter 2 presents context and background relevant to the design of interactive systems for dance learning. It includes an overview of dance skill acquisition and presents existing methodologies and technologies to support embodied practice and dance learning.

Chapter 3 reports on two studies with advanced contemporary dancers to reveal some of the mechanisms at play during dance learning, with a focus on dancers' perspective. I propose a set of opportunities for design: "Extract implicit movement variations and make them explicit", "Save a tangible trace of the learning process", "Provide a palette of tools based on learning techniques", and "Support personalization of learned movement".

Chapter 4 draws from Chapter 3 and introduces *MoveOn*, a technology probe to support and capture video segmentation during dance learning. I deployed *MoveOn* in a workshop with six dancers to investigate how dancers learn and segment a dance choreography.

Chapter 5 describes a structured observation where I examine the potentiality of *MoveOn* to teach dance. I examine how a teacher can

use *MoveOn* to structure and influence students' practice. I compare teacher's and dancers' segmentation strategies and how dancers learn on their own compared with a teacher-created segmentation.

Chapter 6 reports on a 12-month longitudinal study conducted with a dance company re-staging a contemporary dance piece. I move from a solitary vision of dance to a more complex and collaborative process. I analyze the role of artifacts crafted by the group and show how dancers produced an ecology of artifacts to decompose the choreography into simpler components, distribute their knowledge with other learners, and create a common structure among the group. All these processes allow the group to improve its learning process collectively.

Chapter 7 reflects on the challenge of designing interactive systems to support the learning process of contemporary dancers. I discuss the process of reifying implicit knowledge and the challenge of segmenting dance videos. I conclude with limitations and perspectives for future research.

2

Background and Context

This chapter introduces the context and theoretical background relevant to the design of systems for understanding and supporting the practice of learning dance. It details the wide range of techniques that dancers employ during their training. It describes essential psychology concepts behind motor skill acquisition, with an emphasis on dance skills. Then it describes different methods to Finally, it presents technologies designed to support the process of learning dance.

Today, many artists and dance practitioners integrate technology into their dance practice. Technology is seen as a tool to produce interactive performance [Fdili Alaoui, 2019], preserve dance cultural heritage [Forsythe and deLahunta, 2011], and enhance creativity [Schiphorst, 1993]. However, according to El Raheb et al. [2016b], the use of interactive technologies in dance education is an unexplored domain and relatively immature. They suggest that there are still many technological and methodological challenges to be addressed, especially with regard to interaction methods and learning models [Raheb et al., 2016].

This chapter discusses work related to the design of interactive technology for dance learning. It presents a general context for the practice of dance and dance acquisition. It underlines that learning to dance is more than learning individual movements and encompasses a wide range of physical and cognitive skills. Then, it reviews different approaches to design for embodied practices coming from the field of human-computer interaction (HCI). Finally, it presents existing tech-

nologies supporting dance learning and describe how they support the variety of practices presented.

2.1 Dance skill acquisition and practice

To understand how dancers learn complex dance sequences, I present basic motor learning mechanisms, such as memory and knowledge. Then, I present the role of practice and how dancers implement it in their practice

2.1.1 Skill acquisition

Understanding how dancers learn movements can be approached through the lens of motor learning. Motor learning is usually defined as "*a relatively permanent change in the ability to execute a motor skill as a result of practice or experience.*" [Haibach et al., 2011]. Another definition identifies that motor learning is a set of processes by which one is able, through practice, to perform motor tasks better, faster, and more accurately than "baseline" [Shmuelof et al., 2012, Diedrichsen and Kornysheva, 2015]. The baseline should be understood as the performance level of the same motor tasks by any individuals that would perform them. Hence, motor learning relies intensively on practice. However, in the case of dance, learning practice is an umbrella term that encompasses a wide range of concepts.

2.1.2 Dance practice

Practice is central to the acquisition of any motor skill [Wulf et al., 2010], but the factors that constitute "good" practice are not fully understood in the literature. Learning and performing dance choreography requires practice and skills that dancers develop throughout their experiences, such as strength and balance [Golomer et al., 1999]. The acquisition of dance skills at the professional level involves "*deliberate practice*", i.e. "*individuals' prolonged efforts to improve performance*" [Ericsson, 2014]. Dancers do not only "practice" motor tasks, but they deliberately and intentionally engage in performing them with attention and motivation to improve.

In addition, there are various dance practices, ranging from performing ballet to contemporary dance, each style encompassing its own learning style, techniques, and philosophy [Karin, 2016, Enghauser, 2003]. Contemporary dance involves both athletic and artistic training and incorporates elements from many dance styles, mixing codified

techniques with improvisation elements [1]. Although practice is a necessary condition to reach expert performance, each dancer engages in practice differently [Mainwaring and Krasnow, 2010].

[1] https://enfinitiacademy.wordpress.com/2018/10/31/what-is-contemporary-dance-and-modern-dance/

2.1.3 Dance techniques for skill development

Dance practice encompasses many dance learning techniques. Kirsh [2013] studied dancers from the McGregor company. He compared the effect of three dance techniques on movement technicality, memory, timing, and dynamic. The three techniques were marking, performing the movement "*in a less than complete manner*"); full-out practice, performing the whole movement; and mental simulation of the movement. He found that, within this dance company's specific context, marking was the most effective overall strategy to improve memory, technicality, and timing of the movement, while full-out practice seems better for rehearsing movement dynamics. This experiment suggests that dancers can employ different techniques to train specific aspects of the movements. Today, contemporary dance classes often incorporate other disciplines like yoga, Pilates, or somatic practices (Alexander's technique, Feldenkrais' method) to train dancers focusing on elements such as their sensations and perception of their body [Sööt and Viskus, 2014].

The challenge for dancers seeking to learn a specific skill is to select the right technique at the right time. It requires experience and critical thinking [Hodges et al., 2011] and encompasses abilities such as the ability to interpret, analyze, or evaluate one's own movement [Ambrosio, 2015, Facione et al., 2011]. In a typical dance class, teachers are often in charge of controlling how practice is implemented. They structure and control which exercises are executed and what the students should do. However, students' ability to develop reflection skills is increasingly important in today's dance education [Warburton*, 2004]. Today, teachers and choreographers teach and guide dancers to evaluate their performance and plan their practices [Chen, 2001]. Thus, dancers can construct schemes to self-evaluate, plan, or monitor their activities while learning.

Mainwaring and Krasnow [2010] present 16 guidelines for dance teaching. Beyond teaching physical skills, they argue that a dance teacher should establish clear goals and expectations, discuss the influences that affect the dancer's progress, and define the class structure and content. Raheb et al. [2019] present four teaching methods that encompass different ways of teaching dance:

- **Mimetic method**: Students observe and imitate the teacher's movements and learn through imitation.

- **Traditional method**: The teacher provides feedback to dancers on their movements and explains what they should correct to achieve good performances.

- **Generative method**: The teacher gives students a specific exercise and students generate new material and movements following the exercise. The generative method pushes students to reflect and generate new movements and dance phrases.

- **Reflexive method**: The teacher gives an image or a task, and the students improvise without trying to achieve a specific phrase or sequence. Similarly to the generative method, the reflexive method focuses more on generating movements, but with an emphasis on specific aspects, such as movement qualities, equilibrium, and balance, etc.

An effective dance teacher should be able to juggle between these different techniques. On the one hand, the mimetic and traditional methods are based on an academic tradition and are the most dominant teaching methods in dance education [Harbonnier-Topin and Barbier, 2012]. They are mostly used to teach the perfect execution of a movement. On the other hand, reflexive and generative methods encourage students' self-reflection and improvisation abilities, which are essential skills in contemporary dance. However, these methods are mainly focused on the teacher's perspective.

2.1.4 Stages of motor skill acquisition

More focused on the learner perspective, Fitts and Posner [Fitts and Posner, 1967] proposed a behavioral model of motor learning that identifies three main stages in motor skill development: the cognitive stage, the associative stage, and the autonomous stage. A common assumption within the skill acquisition literature is a learner goes through different stages before learning a movement:

- **The cognitive stage** involves the explicit setting of the goal and the actions to achieve it. In this stage, learners' movements are slow and inconsistent, and a large part is controlled consciously. Similarly, Adams [1971] stresses the importance of non-motor operations in early learning and shows that the verbalization of action plays an important role. For example, when an individual wants

to learn how to ride a bike, it is important to understand how the bike works, look for the brakes and the pedals, and verbalize future actions.

- **The associative stage** involves both explicit and implicit actions. The learner has a clear mental image of the end goal and the actions to reach this goal. In this stage, the agent consciously prepares, plans, reflects or reprograms the sequence of movements, but the movements themselves are, for the most part, automatic. For example, here, the apprentice cyclist concentrates consciously on pedaling and keeping the handlebars straight. However, the micro-movements used to maintain balance are controlled automatically.

- **The autonomous stage** involves mostly automatic motor performances where the cognitive resources required for the execution of the skill are minimal. Learners no longer have to think about their movement and turn their attention to the environment, planning their future actions and strategy. For example, the agent becomes a cyclist champion and is actively planning new strategies to surpass other cyclists.

Fitts and Posner underline the fact that motor learning encompasses both conscious and unconscious mechanisms. Krakauer et al. [Krakauer et al., 2011] stress the importance of cognitive strategies in learning motor skills: "*Even if the endpoint of learning is an implicit, procedural skill, the process of arriving at that skill is, in most cases, a richly cognitive enterprise.*". Finally, once learned, motor skills become mostly automatic and unconscious, which refers to the notion of implicit knowledge.

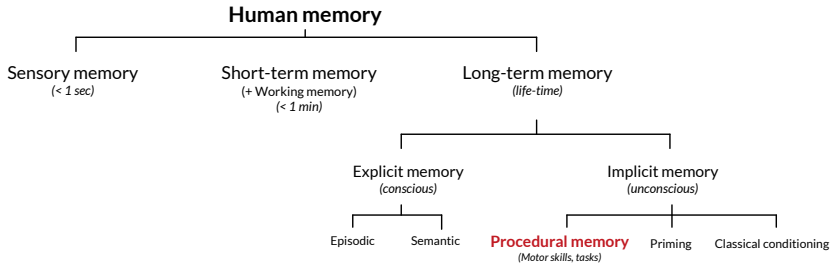


Figure 2.1. Human memory comprises sensory memory, short-term memory, and long-term memory. Long-term memory encompasses explicit and implicit memory. Explicit memory stores conscious and factual information that can be verbalized and easily retrieved. Implicit memory stores unconscious knowledge that cannot be verbalized. Motor skills, such as dance movements belong to procedural memory.

2.1.5 Implicit and embodied knowledge

In 1966, Michael Polanyi [2009] stated that "*We know more that we can tell*". Polanyi introduced the idea that some knowledge cannot be adequately articulated with words. Kirsh [2009] defines this knowledge

as *implicit*: knowledge that cannot be verbalized nor elicited spontaneously by a person [Kirsh, 2009, Stevens and McKechnie, 2005, Opacic et al., 2009]. Kirsh argues that implicit knowledge encompasses a wide range of notions, such as the memories of past events, body movement, a taste, a sound, etc. Tanaka [2013] defines a specific type of implicit knowledge that he calls "*embodied knowledge*": the type of knowledge in which the body knows how to act without being conscious of all the procedures required. Embodied knowledge is thus related to the notion of automatic motor skills presented by Fitts and Posner. Once acquired, motor skills are embodied, and learners can perform them automatically, without cognitive effort. Expert dancers then construct a vast set of embodied knowledge through experience that is now "imprinted" in their bodies.

Embodied knowledge is a specific type of implicit knowledge, which implies that it is difficult to express in words. Yet, Kirsh describes that implicit knowledge can be revealed through appropriate methodology using non-verbal forms of expressions such as illustrations, movements, and artifacts [Kirsh, 2009, Polanyi, 2009]. Moreover, in the previous section, we saw that the creation of embodied knowledge, such as motor skills, encompasses a large part of cognitive activity. This signifies that we can capture embodied knowledge by studying real dance learning tasks. In the next section, we will see that the HCI community has a strong interest in embodied knowledge and provides methodologies to capture it.

2.2 Methodology to design for embodied practice

With the surge of the third wave of HCI [Bødker, 2006], the HCI community considers people's bodies and experiences as a rich source of inspiration for designing everyday technologies. Loke and Schiphorst [2018] describe this direction as the "somatic turn" of HCI. The term *soma* was introduced in HCI by Shusterman [2011] to express the entanglement between the body and the mind. HCI researchers interested in understanding felt-experience and embodied knowledge, reused and design new methods to retrieve such knowledge. I present some of these methods in the following.

2.2.1 Interviews to articulate embodied experiences

Interviews are useful for accessing and articulating subjective experiences. Vermersch [1996] developed the explicitation technique, a

method of interview to elicit felt experiences. Anne Cazemajou successfully followed this method to guide dance students towards the evocation of their experience in a dance class [Cazemajou, 2014]. Based on Vermersch's technique, Françoise et al. [2017] were also able to collect unique experiences and detailed insights of singular body experiences in dance exploration sessions. The particularity of their method was to use an interactive sound installation system called *Still, moving* to make dancers reflect on their sensation. More recently, Fdili Alaoui [2019] used the elicitation technique to retrieve the subjective experience of two dancers performing an interactive dance piece.

Another interview technique is the critical incident method presented by Flanagan [1954]. The interviewer's goal is to focus on emphasizing a specific recent incident that happened to the participant. The interviewee is asked to reflect and provide as many as possible details on this incident. Fortin [1988] employed this interview to help dancers recall and reflect on their experiences in learning modern dance. Mackay [2002] introduced a variation of Flanagan's critical incident technique for HCI. Instead of reflecting on an incident, the participant is asked to reflect and provide as much detail as possible about a specific object, event or process. This technique were successfully used as input for the design of interactive technologies [Caramiaux et al., 2015a, Ciolfi Felice et al., 2016b].

2.2.2 Felt experience and embodied knowledge as a design method

Most methods that focus on embodied experiences emphasize the importance of emotion and felt experiences. Articulating embodied experience requires taking the emotions and sensations of users into account. Schiphorst introduced somaesthetics in HCI as an approach to embodied interaction design [Schiphorst, 2011]. She promotes lived experience and attention to experience as valuable tools for interaction design. Based on this approach, Höök [2018] proposes the Somaesthetic Appreciation design as a theoretical foundation to design for the lived and felt experiences. This method follows a user-centered approach and merges Feldenkrais body-based practice, pragmatist aesthetics, and phenomenology [Höök, 2018]. It encourages the understanding of bodily experiences and places the users' felt experience at the center of the design process through four qualities: subtle guidance, intimate correspondence, making space, and the articulation of experience [Höök et al., 2016]. Around this line, Höök proposes the *first-person perspective*, promoting self-observation and exploration of one's own experience [Höök et al., 2018] to design for the body. Höök implements the first-person perspective to analyzes her own practice

of learning horseback riding. She describes her experience and translates it to design considerations, showing the value of body experiences as a design resource. Among this line, body-based methods for retrieving and sharing felt experiences emerged, such as the *embodied storming*: a physically situated type of brainstorming aiming at expressing and sharing designers' tacit knowledge; or the*embodied sketching*: a method to sketch and articulate embodied experience.

Other approaches propose kinesthetic awareness and movement *connoisseurship* as methods for designing novel and rich embodied interactions. Following this approach, Hummels et al.[2007] argue that designers seeking to design movement-based interaction need to become experts in movement. They provide seven guidelines to support designers in exploring and designing novel movement-based interactions. Loke and Khut [2010] provide an example of applying movement knowledge to the design of interactive tools. They applied somatic practices to design a technology enabling users to be more aware of their inner bodily sensations. Other examples of these concepts include *Move to Design Design to Move* [Wilde et al., 2011] and Moving and making strange [Loke and Robertson, 2013]. Finally, these methods inspired new body-based technologies for dance performance [Eriksson et al., 2019] and dance education.

2.2.3 Movement analysis

Another research area focuses on describing and analyzing human movements to design software. The Laban Movement Analysis system (LMA), initially developed by Rudolf Laban [Von Laban, 1975], is a system used for the description and the analysis of movements. LMA describes human movement in terms of *Body*, *Effort*, *Space*, and *Shape* [Fdili Alaoui et al., 2015b]. The Body category describes which movements are performed, the Effort category describes the shift in attitude, the Space category describes the spatial direction, and the Shape category describes the form of the body [Von Laban, 1975, Bernardet et al., 2019]. LMA system can be applied to any human movement and was used in diverse tasks such as coaching athlete [Hamburg, 1995], analyzing stroke rehabilitation [Foroud and Whishaw, 2006], or interacting with robots [Rett and Dias, 2007]. Fdili Alaoui et al. [2015b] argue that LMA provides a framework for accessing embedded knowledge and making it explicit. They stress the challenge of verbalizing experiences and argue that LMA supports the communication of embodied insights. LMA presents the advantage of being a universal language to categorize any movement within specific categories. It allows dancers and choreographers to talk the same language and verbalize

some concepts that would be otherwise implicit [Fdili Alaoui et al., 2017]. However, using LMA requires specific training that users do not necessarily have and imposes a language that does not necessarily fit users' practice.

2.3 Incorporating technologies into dance performance and learning

Since the 1970s, contemporary choreographers embraced technology for creative purposes, teaching, and playwriting. For example, the choreographer Merce Cunnigham used a computer compositional tool called *LifeForms* to simulate new dance sequences for the piece *Truckers*. Later, *LifeForms* became *DanceForms*, a tool for teaching and produce new choreography [2]. Beyond using technology to enhance creativity, like Cunnigham did, dance practitioners quickly appropriate technology to preserve their practice. Before the rise of digital tools, the embodied and transient nature of dance poses issues for its transmission and preservation [Grove et al., 2005]. But, technology clearly redefined the preservation and the transmission of dance. Bleeker [2016] argues that technological systems designed to make, capture, and archive dance, enhance dance preservation, and redefine how we think about and transmit dance movements. Before videos, dance was transmitted through demonstration from dancers to dancers or via dance notation (Figure 2.3), textual description, drawing, and figures (Figure 2.2). Technology provides a tool for capturing and preserving the dance cultural heritage [3], which facilitates dance transmission and teaching. More recently, multiple collaborations between interdisciplinary teams led to the design of digital systems designed to support dance, including WhoLoDancE [El Raheb et al., 2016a], Motion Bank [Forsythe and deLahunta, 2011], Moving Digits [Do Nascimento Correia, 2019], and the TKB - Transmedia Knowledge-Base - project [Fernandes, 2013]. Each project developed video annotation, motion capture, or augmented reality systems for dance preservation, transmission, and education.

My goal is not to provide an exhaustive list of technologies but rather to provide a set of examples that represent characteristics of each technology and paradigm. Refer to [El Raheb et al., 2016a] and [Alaoui et al., 2014] for a complete list of systems designed for dance learning.

Figure 2.2: Kellom Tomlinson sets forth the principles of Baroque dance in the book *The art of dancing explained by reading and figures* (published in 1735). He describes the positions, postures, and steps of the dancers, a as well as the attitude dancers should adopt with their partner . Source: `https://www.loc.gov/resource/musdi.158.0?st=gallery`

[2] `http://www.credo-interactive.com/danceforms/main.html`

[3] `https://ich.unesco.org/en/RL/gwoka-music-song-dance-and-cultural-practice-repre`

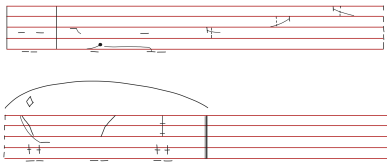


Figure 2.3: Dance notation is a graphical representation of dance movements. Here is represented an example of Benesh notation, a form of dance notation invented by Rudolf Benesh in 1955. Each horizontal red line corresponds to a body part, and the black lines to the dancer's movements and postures.

2.3.1 Video support for dance learning and teaching

The simplest technology to save and transmit dance movement is video recordings. Video is now a common educational resource in dance studios, and professional dancers are trained to learn and reproduce dance choreography from video. For example, the French state diploma of dance teacher training requires candidates to learn a dance choreography from a video recording [4] and perform it during the examination day.

[4] Examen d'Aptitude Technique (EAT) http://www.culture.gouv.fr/Thematiques/Danse/Enseignement-formation-et-metiers

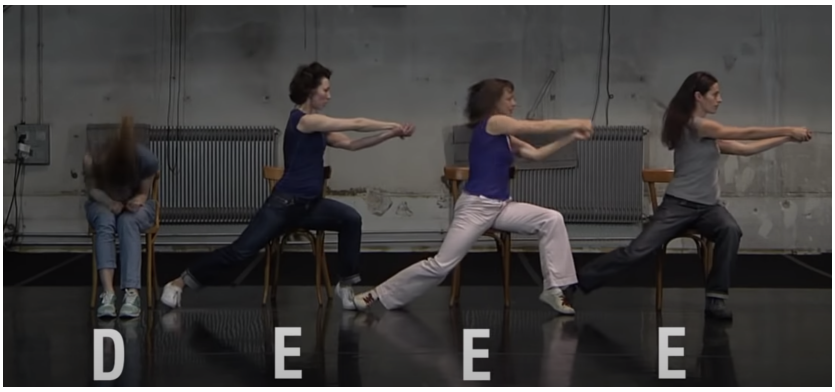


Figure 2.4. In the video series *Re:Rosas!*, Anne Theresa de Keersmaeker and her company teach how to perform the second movement of *Rosas danst Rosas*.

Dance choreographers also take advantage of videos to develop educational tools for their choreography or dance techniques. Through video tutorials, dancers can present, decompose, slow down, and explain movements. For example, in 2013, the choreographer Anne Theresa de Keersmaeker initiated *RE:Rosas!*, a project where she encourages internet users (dancers or not) to learn, appropriate, and perform the second part of *Rosas danst Rosas* [5] (Fig.2.4). With the help of her company, the choreographer produced four tutorials videos where she teaches and explains the vocabulary and the structure of her choreography, allowing viewers to understand and learn the choreography on their own. In *Improvisation Technologies* (Fig. 2.5), the choreographer William Forsythe created a CD-ROM comprising 65 video-lectures. The designers Chris Ziegler augmented the videos by incorporating explicit geometric shapes, allowing dancers to learn Forsythe philosophy and improvisation techniques [Forsythe and Sommer, 1999][6]. Instead of focusing on a specific stage production, this CD-ROM provides insights into the dance techniques created by William Forsythe and his company over the years.

[5] https://www.rosas.be/fr/productions/378-rosas-danst-rosas

[6] http://www.movingimages.de/?type=design&txt_id=10

Finally, video can provide a source of feedback and self-assessment for students practicing physical activities [O'Loughlin et al., 2013]. Krasnow and Wilmerding [2015] argue that letting dance students watch videos of their own performance provides a form of nonverbal

augmented feedback, fostering students' self-evaluation skills [Alves, 2017]. In a recent review, Alves [2017] describes how videos have a significant impact on students' self-perception and self-assessment, and encourages the development of objectivity [Alves, 2017, Leijen et al., 2009]. In the dance studio, Molina-Tanco et al. [2017] proposed the "*delay mirror*", a project based on the capacity of students to reflect on their performance. It consists of a video-based system that renders a video stream of dancers performing, with a 2-3 second delay, that let dancers analyze their movements and the movements of their peers. They used a focus group to investigate how the dancers accepted the technology in the context of a dance class and how it allows dancers to comment collectively on their actions.

Herbison-Evans [1988] argue that video presents issues when used to record and learn dance movements. He raised seven of these issues in the specific case of dance recordings:

- the trade-off between the video quality and the field width,
- the obsolescence of media players and video recorders,
- the use of videotape,
- the hidden movements from the camera,
- the camera's unique viewpoint,
- the influence of the director's; and
- the gap between the choreographer's intent and the performer's interpretation.

Although some of these issues have become less of a concern today thanks to technological advances (video resolution, the switch from analog to digital format), some are inherent to the video media (hidden movement and occlusion, fixed point of view of the camera). Designers overcame some of these issues by developing motion capture, analysis, and annotation tools.

2.3.2 Motion capture tools for dance learning

One of the major advances in the design of interactive tools for dance is the development of motion capture technology (Fig. 2.7). Vision-based systems are used to capture the users' movements and to provide real-time feedback to the user.

Feedback can be used to correct students' execution of a movement. For example, Anderson et al. [2013] proposed *YouMove*, a Kinect-based

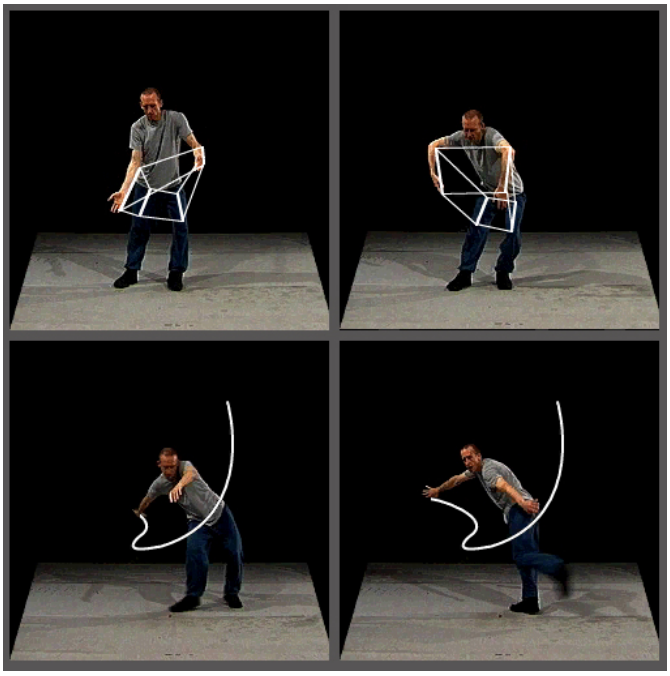


Figure 2.5. William Forsythe uses videos with embedded dynamic lines to document and explain improvisation techniques and principles of his choreography. Here, the white lines form a tangible dynamic object allowing the choreographer to reveal and talk about invisible structures. Source: `https://www.williamforsythe.com/filmspaces.html?&no_cache=1&detail=1&uid=42`

system with an augmented reality mirror. The system displays the movement to perform on a screen and users see in real-time video guidance and feedback on the mirror. The system offers can also instruct which movement to perform and corrects them afterward. Compared to traditional video demonstrations, adding interactivity improves learning and short-term memory retention. Tsampounaris et al. [2016] proposed an even more immersive approach that places the user within a virtual reality environment that provides real-time feedback for the movement. To provoke self-reflection, they used avatars and visualizations in a gaming context that push the user to mimic kinetic material.

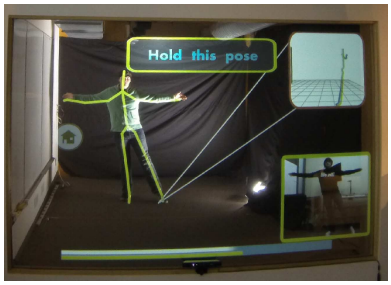


Figure 2.6: *YouMove* provides feedback through an augmented reality mirror, allowing users to learn physical movements. Source: [Anderson et al., 2013]

Feedback can also be provided to make students reflect on their movements. Bevilacqua et al. [2011] propose a system called *If/Then*, which tracks and follows the user's gesture in real-time to control videos of the choreographer Richard Siegal performing the "real" movement. These videos guide users as they learn the choreographer's vocabulary, encouraging dancers to explore the qualities of each dance movement, rather than simply imitating it. Further work by Fdili Alaoui et al. [2015a] includes a pedagogical installation for learning movement qualities stemming from the vocabulary of choreographer Emio Greco. In collaboration with his dance company, Emio Greco | PC, they implemented an interactive pedagogical installation for their workshop *Double Skin/Double Mind*. This installation provides augmented

video information and real-time visualization of the company's dance movements qualities that they developed. The authors showed that their system can recognize predefined qualities and respond to them with interactive sound and visuals. It allows dancers to better learn the company's vocabulary, explore it, and personalize it. From the same author, *A light touch* is an interactive installation based on the recognition of movement qualities (based on LMA) [Fdili Alaoui et al., 2012]. They suggest that the installation enhances users' experience and promotes the exploration of movement.

Although these interactive systems are based on motion capture, their learning paradigm is quite different. Some systems aim at supporting the perfect execution of a movement, while other push students in engaging and reflecting on their movements.

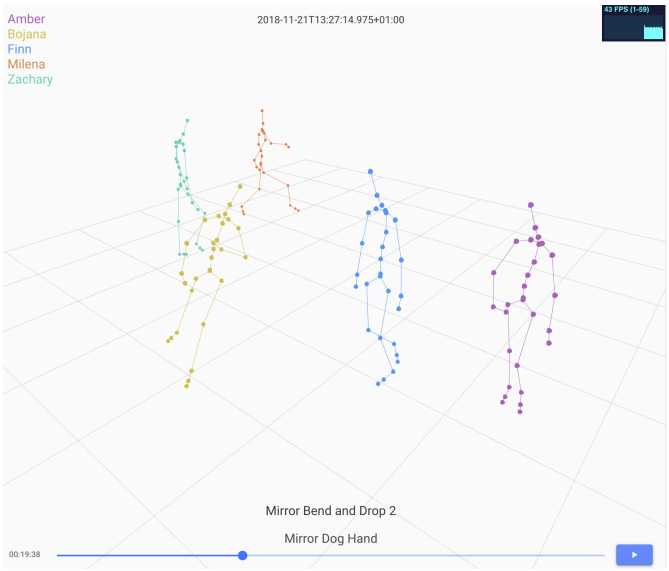


Figure 2.7. Motion capture of five dancers from the dance piece "Effect" by Finnish choreographer Taneli Törmä.
Source: `http://choreographiccoding.org/labs/mainz-2019`

2.3.3 Annotation tools for dance learning

Annotation tools are another type of technology that supports the learning process of dancers in a variety of ways [Alaoui et al., 2014, El Raheb et al., 2018]: On the one hand, researchers created dance archives and art repositories which offer efficient ways for classifying, navigating, and searching in large dance multimedia databases [Forsythe and deLahunta, 2011, El Raheb et al., 2018]. Ramadoss and Rajkumar [2007] created a semi-automated system that annotates and retrieves dance videos, whereas El Raheb et al. [2016c] created a manually dance annotation system. On the other hand, researchers created annotation tools to enhance the choreographers' creative process. For example, Cabral et al. [2011] designed a multi-modal annotation tool

that allows choreographers to regroup and annotate a set of choreographic objects and to share it with dancers. This project was extended to a 3D environment to allow users to view and annotate from multiple angles [Ribeiro et al., 2016].

Annotation tools offer great potential to enhance dancers' understanding of videos. *The Choreographer's notebook* is an example of an annotation tool used in a real dance pedagogical context. Designed by Singh et al. [2011], *The Choreographer's notebook* is a web-based system application that allows choreographers and dancers to collaborate in analyzing and annotating rehearsal videos. The authors run a field-study of this system in three dance productions [Carroll et al., 2012] and argue that it increases rehearsal time efficiency, support learning, and enable online communication between dancers and the choreographer. However, they found that dancers do not use this tool to comment on each other's performance and that choreographers make most of the comments, suggesting a hierarchy between dancers and choreographers. Recently, dos Santos et al. [2018] presented a video annotation tool specifically designed to support dance teaching, where dance instructors annotate videos of their students, providing feedback, either with predefined labels or using their own vocabulary.

DanceNote created by the company *La fabrique de la danse* is a web platform for studying sharing dance videos. It provides the possibility of annotating documents, sharing documents, chatting, uploading and downloading dance videos, synchronizing several videos, and switching from different perspectives. *DanceNote* is more than an annotation tool and provides a platform for teaching, learning, preserving, and producing dance. *Synchronous Objects* 2.8 was developed for William Forsythe's *One Flat Thing, reproduced*. This initiative focuses on documenting and revealing deep structures of choreographic ideas through a collection of interactive visualizations and tools [Palazzi et al., 2009]. Dancers can use this system to go through William Forsythe's philosophy and learn more than just movements. Along the same lines, *WebDance* [Kavakli et al., 2004] is an e-learning platform for the learning of traditional dance. This tool use video, 2D and 3D graphics, interactive images, and text to provide lessons.

Finally, David Rittershaus, a researcher and artist from the Motion Bank project [7] argues that a perfect method to annotate dance pieces doesn't exist. Annotators have their annotation methods according to their project, objective, and interest. The strength of annotation tools is that they do not impose rules on the user. Instead, they provide a palette of tools that can be used in many ways to support learning and

[7] https://medium.com/motion-bank/introduction-to-annotation-as-a-research-practice-

Figure 2.8. ***Synchronous Objects* - William Forsythe's *One Flat Thing*.**

teaching.

2.4 Chapter summary

This chapter discusses work related to the design of interactive technology for dance learning with a focus on dancers' practice and embodied experience. I first reviewed some motor skill mechanisms to understand how human beings embody new motor skills. Then, I underlined that dance learning is not only performing perfect movements, but involves a richer set of skills. In the second section, I gave an overview of methodologies emphasizing the importance of understanding users' practice, felt-experience, and sensation to design movement-based systems. I emphasized that the main challenge faced by these methods is to capture and reveal non-verbalizable forms of knowledge. I gave an overview of different initiatives taken to support dance learning through interactive technology. These tools support either the dance performance itself or the learning and rehearsal process. Finally, I stressed that the literature on dance pedagogy is primarily focused on a teacher's perspective and there is a lack of empirical understanding of dancers' perspective.

3

Understanding Dancers' Perspective on Learning

This chapter presents two studies conducted with advanced contemporary dancers. Both studies seek to reveal some of the mechanisms at play during dance learning, with a focus on the perspective of the dancers.

This chapter contains written material published in [Rivière et al., 2018] [1] *and includes part of the work presented in [Rivière et al., 2019]* [2]*. These two papers were a collaborative effort conducted with Sarah Fdili Alaoui, Baptiste Caramiaux, and Wendy Mackay. I was the lead and corresponding author on both of these papers.*

Dancers have to combine athletic performance to execute complex dance techniques, with expression and aesthetics. Dancers embody learning schemes and knowledge, through experience, that are partly implicit to them. I argue that embodied knowledge forms a rich source of opportunities to design technology supporting dance learning. To reveal some of the dancers' embodied knowledge, I followed a first-person perspective methodology, placing the dancers' lived experience at the core of the design process [Höök et al., 2018]. I recruited experienced contemporary dancers, compared to novices, expert dancers already developed a set of knowledge, have extensive experience taking dance classes and are more inclined to retrieve and talk about their perceptions [Fdili Alaoui et al., 2015b].

I conducted two studies on dance movement acquisition to understand

[1] Jean-Philippe Rivière, Sarah Fdili Alaoui, Baptiste Caramiaux, Wendy Mackay. How Do Dancers Learn To Dance?: A first-person perspective of dance acquisition by expert contemporary dancers. *MOCO 2018 - 5th International Conference on Movement and Computing, Jun 2018, Gênes, Italy. MOCO '18 Proceedings of the 5th International Conference on Movement and Computing, pp.1-8,* <10.1145/3212721.3212723>. <hal-01849604>

[2] Jean-Philippe Rivière, Sarah Alaoui, Baptiste Caramiaux, Wendy Mackay. Capturing Movement Decomposition to Support Learning and Teaching in Contemporary Dance. *Proceedings of the ACM on Human-Computer Interaction , Association for Computing Machinery (ACM), 2019, Proceedings of the ACM on Human-Computer Interaction, 3 (CSCW), pp.1-22.* 10.1145/3359188ff. hal-02378487f

how dancers perceive and report on their own learning processes. My goals were to retrieve, capture, and reveal dancers' experiences and embodied knowledge on learning and provide implications for designing tools supporting dance learning mechanisms.

This chapter presents two studies. Study 1 focuses on 11 semi-structured interviews with contemporary dancers, where I seek to elicit dancers' learning processes. Study 2 focuses on four dancers reporting on their learning process with documentation materials. I discuss the benefits and limitations of technology-free documentation to capture dancers' practice and embodied knowledge. I extracted four design implications from the results to support real dance learning processes and behaviors I observed.

3.1 Study 1: interviews with dancers

To create tools to support the learning of dance, it is important to first understand dancers' learning processes. I conducted an interview study with 11 professional dancers to discover their techniques to learn a new dance piece. With this study, I aim to present the various techniques used by dancers during their training, the mechanisms that appear during the learning process, and their learning steps and progression.

3.1.1 Participants

I recruited 11 professional contemporary dancers (six women; five men) with 7 to 34 years of experience (M=18.3, SD=8.3). The participants were recruited during an international dance event in the *Centre National de la Danse* (CND) that took place in Paris: Camping 2017 [3], and through Sarah Fdili Alaoui's contacts. The participants were not financially compensated.

[3] https://www.cnd.fr/fr/page/298-camping-2017

3.1.2 Procedure

I conducted a series of semi-structured interviews focusing on the perspective of dancers learning and practicing movement. I used a variation of the Flanagan's Critical Incident Technique [Flanagan, 1954] introduced by Mackay [Mackay, 2002] for HCI, and subsequently used as an input to design [Caramiaux et al., 2015a] and evaluation [Hartson and Castillo, 1998]. Critical Incident Technique helps participants recall situations and describe why they may be atypical. I applied this technique and asked the participants at the beginning of the inter-

view to recall the last time they had to learn a new dance movement in order to retrieve specific examples and avoid generic answers. The interviews were built around four topics through four main questions:

- **Learning Steps**: "*Can you explain how you learn a dance movement step by step? What do you think are the most important steps?*"
- **Movement Transformation**: "*Do you make any changes in your movements during the training and why?*"
- **Understanding of the learning endpoint**: "*When do you consider the movement to be learned?*"
- **Using additional information**: *"Do you use any cues or feedback to learn the movement?*"

Each interview was conducted face to face in different venues in France (Paris: 8, Toulouse: 3). Interviews were conducted in French (quote translated from the French) and lasted for approximately 30 minutes.

3.1.3 Data collection and analysis

I recorded audio and took handwritten notes during the interviews. Together, with Sarah Fdili Alaoui, we performed a thematic analysis [Guest et al., 2011] from the corpus of the collected data to identify, analyze, and report themes within the data from the interviews. I transcribed the interviews, read the transcriptions, and highlighted relevant strategies reported by the participants on the way they learn dance movements. This process produced the 'initial codes' of the data.

We annotated the initial codes on sticky notes using words from the participants' subjective verbalization. We displayed the sticky notes (physical annotations) on a large plane surface and grouped those related to each other (see example in Fig. 3.1). Displaying sticky notes added flexibility, allowed collaboration between us, and enabled cross-verification of our coding, annotations, and clusters. Each cluster formed a concept that we named with terms that summarize them. We finally grouped the concepts into themes. Themes provide a way of articulating the data collected and the concepts identified. In the example depicted in Fig 3.1, each column represents a concept, the "sticky notes" on top of each row represents the name of each concept (Observation, Imitation, marking, and segmentation), sticky notes below are summaries of dancers' sentences. These four concepts repre-

sent a theme *Learning Techniques*.

According to the recommendations of Cho and Lee [2014] on the analysis process, we started the analysis before all the interviews were conducted.We followed three iterations: the first iteration was performed on responses from the first four participants, then we iterated on the following four, and lastly, we performed the analysis with responses from the last three participants. These iterations allowed us to refine the analysis twice, verify it with further participants, and guide subsequent data collection. For example, after the fourth interview, in order to retrieve more specific data on variations, we refined the questions "*Do you use the variations of your movement to learn more easily?*" to "*Do you make any changes in your movements during training and why?*". In the following, I anonymized the interviews and refer to the dancers as participants 1 to 11, denoted by P1 to P11.

Figure 3.1. First iteration of the thematic analysis. Initial codes from the interviews are grouped in columns. On top of each column, a term describes the codes, such as observation or imitation. A theme is finally defined gathering a set of concepts.

3.2 Results

We identified two themes: *learning progression*, which regroups the different steps and mechanisms that take place over time, and *learning techniques*, which groups the actions that dancers reported using during their learning process.

3.2.1 Learning progression

The dancers reported five important steps in their learning progression: *analysis*, *integration*, *fluidity*, *personalization*, and *implicit variations*.

3.2.1.1 *Analysis*

All the participants reported that the first step in the learning of dance movement is an analysis step that includes several actions ranging from observing the movement to replicating it. Importantly, the actions of the dancers seem to be made with the goal of reducing the complexity of the movement at the beginning and gradually increasing it:

> *In the beginning, it's just the frame. As I move forward, elements will be added. I'll do it chronologically. I refine every movement.* (P6)

Therefore, complexity seems to be understood as the level of detail in the movement, which is increased from a coarse analysis, "*the frame*" (P6), to further refinements through the addition of details.

3.2.1.2 *Integration*

Almost all participants (10/11) reported that, through repetition, the movement gradually becomes integrated into the body. The word "*integration*" was used to refer to an incorporation of movement mainly at the motor level. A movement is perceived as being integrated when the cognitive load, exerted by the dancer during the movement execution, is reduced. They do not think about the movement they want to perform anymore:

> *[I know that I integrated a movement] when I can reproduce it naturally. Naturally, because the movement is inside of my body, it is integrated into my body and I don't need to think about it anymore. It's more the body that goes and realizes the movement.* (P3)

3.2.1.3 *Fluidity*

The participant reported that the movement of integration is characterized by the movement qualities: "*natural*" (P7, P3), "*fluid*" (P3), and "*organic*" (P2). Most of the dancers (6/11) reported that a movement is integrated when it is smooth, fluid and they don't have to think about it. Interestingly, end-movement fluidity (or movement smoothness) has recently been considered as one criterion to assess motor skill acquisition [Shmuelof et al., 2012].

> *You know a movement [...] when you don't think about it, when it comes out smoothly, just by pressing the start button.* (P7)

3.2.1.4 *Personalization*

Seven participants reported "personalizing" the movement. This relies on changes that the dancers apply to appropriate the movement according to their individualities such as body characteristics or ex-

Figure 3.2. Interview with a contemporary dancer in a dance studio.

pressive range. Personalization is the moment when dancers can "*deconstruct, deform and give qualities*" (P11), "*bring his own touch*" (P1) or "*doing it according to your body your ability, your sensation and your feeling*" (P9). According to P4, this step has an active role in learning: "*There is no learning without appropriation*". One of the characteristics of personalization is the use of specific explicit variations. Seven participants reported adding explicit variations only when the movement is integrated. We call *expressive variations*, these explicit variations used by a dancer as a means of expression. P2 stated that *expressive variations* are a way to go beyond what they have learned in dance classes, to "*step outside the framework of dance class*" and "*take liberties*". These variations bring "*different intensities, subtleties, movement qualities or interpretations*" (P2).

3.2.1.5 Implicit variations

Almost all participants (8/11) reported that implicit variations appear all along the process of dance acquisition. These variations are perceived by participants as non-volitional actions, in other word, variations that they cannot control. P8 perceived them as personal body signatures: "*We all have some kind of body signature that is different from others*" (P8). These signatures characterize the dancer and are present across the different steps of learning "*To some extent, there are always changes brought to the movements. Movements are transformed because different bodies produce it.*" (P7). P2 argues that it takes years of practice to shape a body and that this shaping has an effect on the movement: "*It takes years of repetition, the body is forming and there's body memory.*".

Finally, dancers also perceived that the movement has an inherent trial-to-trial variability.

> *The movement moves all the time even when you feel like you're learning the same thing, it's never fixed... The same movement won't be the same thing. Because you matter, your body. As a dancer you evolve.* (P11)

3.2.2 Learning techniques

The second theme regroups the various techniques used by the dancers during the learning process. It consists of specific actions that allow them to acquire movements. We identified the following seven techniques: *observation*, *repetition*, *imitation*, *marking*, *segmentation*, *mental simulation* and *personal adaptation*. Fig. 3.3 depicts these techniques with regards to the reference movement to be learned.

3.2.2.1 Observation

All participants reported the observation of the movement as the very first action of the learning process. A dancer can observe the movement at several levels of detail. The participants mentioned that they observe "*the energy*" (4/11), "*the rhythm*" (4/11), "*the space*" (4/11), "*the direction*" (P6, P10), "*the impulse*" (P3), "*the form*" (P9), "*the musicality*" (P11), or "*the orientation*" (P10). Observation is an iterative action and is carried out throughout the learning process:

> *I'm trying to see the big picture, I'm looking at it from different angles. You are brought to see it [the movement] several times. The first look is global, I look at the energy, the situation in space, the most important ones. My second look will focus on the details and see how the energy flows, what is the initiation of the motion in the phrase.* (P3)

A dancer can also observe various isolated elements that contribute together to the global movement.

> *Firstly it's observation, I observe the teacher, the dancer or the choreographer. I observe the movement and then I try to understand, how the movement is technically constructed, then I look at the rhythm, the musicality, the energy.* (P11)

3.2.2.2 Repetition

Dancers constantly mentioned repetition as the way to progress in learning. For P11, the movement becomes automatic thanks to repetition: "*We do it several times until it becomes an automatism*". The repetition of a movement can last several days; P5 estimated 4 to 5 days to reach the perfect movement. P7 describes the repetition of the movement as longitudinal to the learning that can "*last as long as you want*"

(P7) and depends on the "*level of requirement*" (P7).

3.2.2.3 Imitation

All participants try to imitate the reference movement exactly: "*The most similar possible, otherwise it's not the same. I'm trying to make the repetition as accurate as possible until it's assimilated.*" (P1). The criterion of success is based on how similar the movement is to the reference in its global form.

3.2.2.4 Marking

More than half (7/11) of the participants reported that they decompose the reference movement to work independently on "*space*" (P5, P6, P7, P9), or "*time*" (P7, P9). P2 described starting their training with a smaller movement, with less energy or with one part of the body. P8 compared marking to "*sketching the movement*".

> *There are also other parameters to adjust when realizing a choreography, there are others dancers, the space I use and the one we share, the time I have and the one we share. And I want to work on these things in isolations. That's why the movement is therefore marked.* (P7)

3.2.2.5 Segmentation

More than half (6/11) of the participants reported to segment the reference movement into smaller sequences. (P8) "*I will work on elements in isolation and repeat them, more often the problematic ones*". These isolated sequences must be understood here as temporal segments of the reference movement that have a clear beginning and end. Segmentation can be used to isolate problematic sequences, work on them separately and recombine the whole movement: " *I'm going to work and repeat elements separately, often those that are problematic.*" (P7).

3.2.2.6 Personal adaptation

Five participants mentioned the use of personal adaptation. We call *personal adaptation* the explicit variations used to make a movement easier to execute. *Personal adaptations* appear when the dancer has difficulties in producing specific movements. In this case, the dancer can modify the movement to make it easier to perform. For example, P7 mentioned a fall on the ground that she could not perform in time because of her height. She used her hands even though they were not part of the reference movement.

3.2.2.7 Mental simulation

Three participants refer to mental simulation to support movement memorization. Instead of physically executing the movement, dancers

can mentally simulate the movement: "*sometimes, during the evenings, in bed, I like to go over the whole piece but, in my head. I see myself dancing*" (P5).

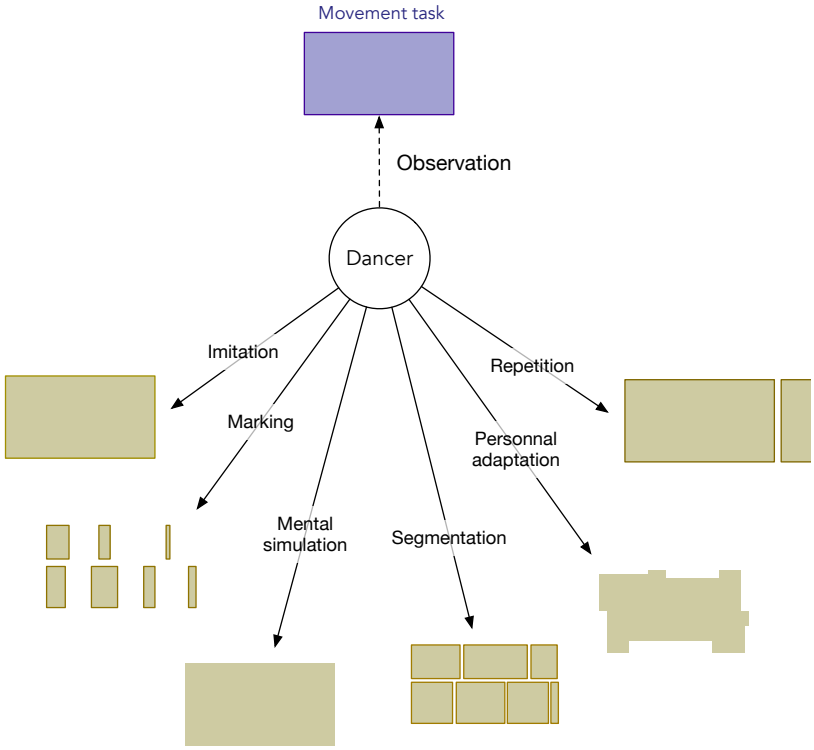


Figure 3.3. The different techniques used by the dancers during dance movement acquisition. When learning a new movement (purple square on top), the dancer uses movement observation, imitation, marking, mental simulation, segmentation and variations (see descriptions in text).

3.3 Study 2: Documenting learning with documentation materials

The interviews revealed the different steps of learning but lack detail. To push further the understanding of dancers' learning practice, I conducted a second study in a dance studio that focused on the real-world process of learning dance. I asked four contemporary dancers to learn a dance solo sequence from a video recording and document their process with documentation materials.

Based on the results of the first study, we used the learning techniques as a support to help dancers structure their documentation process. Thus, I asked dancers to report when they observe, segment, simulate, imitate, mark, adapt, and repeat movements. In this study, the goal is to understand how dancers report and save a trace of their practice and investigate their needs, their actions, and the problems they

encountered while learning from a video.

3.3.1 Participants

I recruited 4 experienced contemporary dancers (all women, 2 professionals) with 6 to 26 years of experience, all with prior experience learning dance phrases from videos. Participants were invited to lunch as compensation for their participation.

3.3.2 Setup and apparatus

The study was conducted in a dance studio in Paris and lasted approximately two hours. Dancers viewed video on a tablet [4] from a traditional video media player [5]. All participants agreed to participate in the study and signed a consent form validated by an ethics committee. My advisors attended the sessions and participated in the warm-up and the group discussion.

[4] iPad apple iOS 6 version 10.3.3, screen 9.7 2048 x 1536, 14G

[5] QuickTime

3.3.3 Procedure

The study comprises three parts. The introduction presents the research context and describes the upcoming tasks (20 minutes). We then performed a warm-up exercise where each participant created a movement associated with their name. Participants introduced themselves to each other with their names and the movement they created. Then, we put each movement end-to-end, generating a choreography that we repeated together, like an *exquisite corpse* with movements.

Participants had one hour to learn a dance clip. The dance clip is an extract of one minute and forty-seven seconds solo from a dance piece call *SKIN*[6], shot with a hand-held camera, performed by a professional contemporary dancer in a dance studio. The first 30 seconds of the video involve easy slow movements, and the second part involves more difficult fast movements with rotations and changes of direction. We chose this video for its progressive difficulty and because it represents a typical example of videos that dancers can be expected to learn during dance auditions. In parallel, we asked dancers to document their actions and the problems faced during learning by using the following supplies (see Fig. 3.4):

[6] `http://saralaoui.com/2016/02/skin/`

- **Card with the Learning technique names**: observation, segmentation, mental simulation, imitation, marking, personal adaptation, repetition. Plus additional space for comments.
- **Blank cards**: let dancers propose new techniques.

- **Pink sticky notes**: identify a problem encountered during the learning or the use of the video.
- **Yellow sticky notes**: indicate the actions performed on the video.
- **A0-size paper**: allows dancers to place and, compose cards and sticky notes.

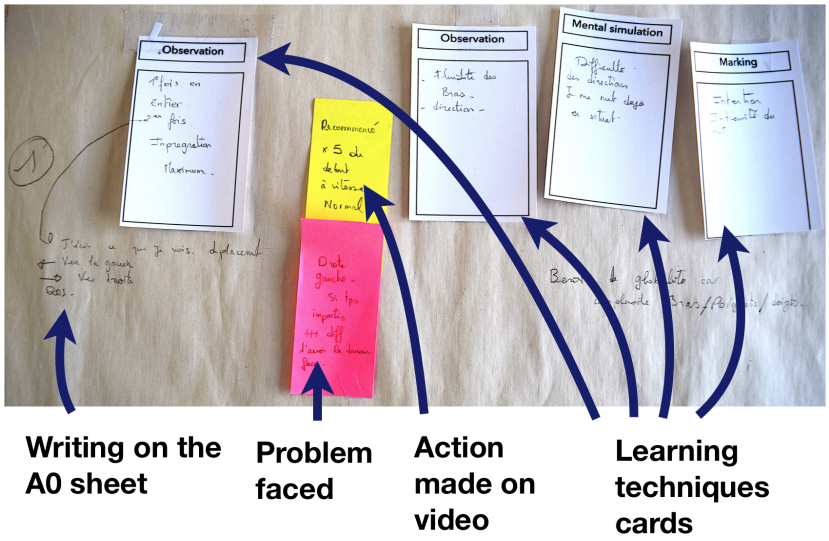


Figure 3.4. Composition example: P1 annotated the learning techniques cards, added yellow sticky notes to document her actions on the video and pink sticky notes to report the problems she faced.

In the following, we refer to the final paper artifacts created by participants as compositions. Importantly, the only requirement for participants was to document and report how they learned the phrase. We did not impose composition rules and let participants develop their own compositions and freely place the cards and sticky notes.

In the last 30 minutes, we asked each participant to perform what they learned from the clip. Finally, we organized a group discussion where the dancers explained their composition and discussed their learning process. Fig. 3.5 and Fig. 3.6 depict the participants as they review the video and explore the choreography.

3.3.4 Data collection and analysis

We took multiple photographs and recorded video and audio of the session. We collected and analyzed the composition created by each participant. I transcribed and analyzed the videos, then with my supervisor Sarah Fdili Alaoui, we iteratively analyzed the participants' compositions, videos, and recordings using thematic analysis [Guest et al., 2011]. We defined concepts by using the participants' words (open coding) and grouped them into themes (axial coding). The analysis was verified and refined by my supervisors in order to converge

Figure 3.5. P1 interacts with the tablet to select the next movement to learn. Her composition, on the right, documents her learning process.

into themes that best captured the data. Each of the researchers involved in the analysis read the transcripts beforehand and was present during the study. The following data refer to the dancers as participants 1 to 4, denoted by P1 – P4.

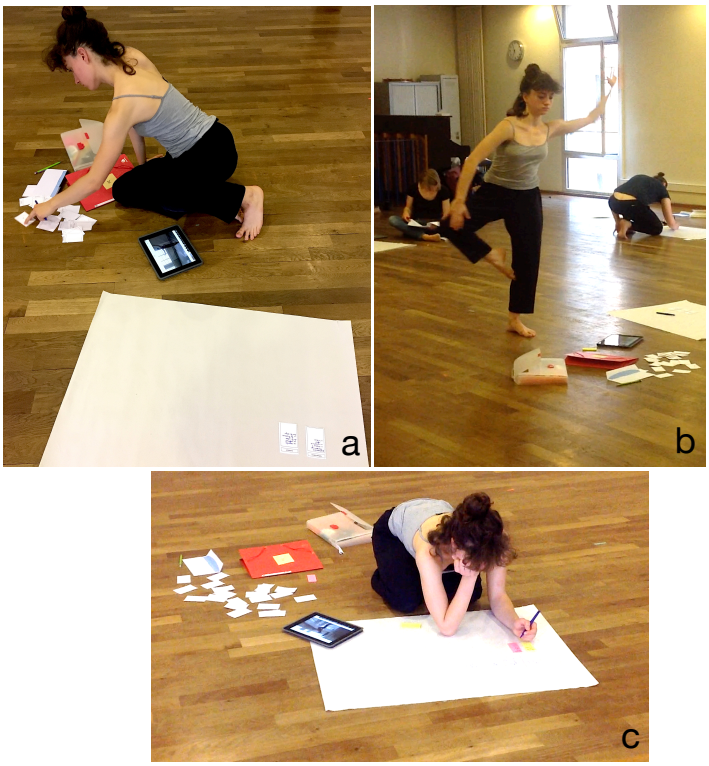


Figure 3.6. (a) P2 picks between different learning techniques, (b) P2 learns the choreography from the video on the tablet; and (c) P2 reports on problems faced during the process.

3.4 Results

All four participants used the different learning techniques, added comments on the cards, and wrote (P1, P4) or drew (P3) on the A0 sheet. Participants learned between 0'42 (P3) and 1'02 (P2) of the proposed phrase. The compositions of P1, P2, and P4 are presented in Fig. 3.8, and composition of P3 is presented in Fig. 3.7.

3.4.1 Learning techniques in action

All the participants were able to report on their learning using documentation materials. Three out of four participants found the learning technique cards sufficiently generic to classify their actions. However, P3 and P4 used blank cards to create two new learning techniques. P3 created a *draw* card to capture the action of drawing the trajectory of a movement. P4 created a *voice* card for the action of verbalizing aloud. P1 said that the learning cards influenced her choices and that she would not have given these particular names to the techniques. We found that the learning techniques were combined rather than isolated from each other. An example of this combination of learning techniques is represented in P3's composition, P3 used two repetition cards (see Fig. 3.7a) linked to the other cards by lines (see Fig. 3.7b). She explains that: "*There are inseparable things [...]. There are some techniques I would not have taken out. It is completely in repetition, everything works at the same time*" (P3).

3.4.2 Movement segmentation

P2, P3 and P4's compositions identified segments of video with *segmentation* cards. P3 segmented the phrase into three parts: 0' - 0'32": easy, 0'32" - 0'36": transition, and 0'36" - 0'40": complex movements. P4 and P2 segmented their learning into 2 parts. P2 indicated decomposing the movement when it became too complex while P4 indicated that she decomposed according to the *diagonals*, that refer to spatial markers of the movement.

P1 did not use segmentation's card in her composition. Her segmentation, however, include clusters of learning techniques, each starting with *observation*. For example: *observation-repetition-personal adaptation* then *observation-mental simulation-marking-personal adaptation*. These clusters identify the learning of the different parts of the phrase.

The dancers segmented the dance phrase in a personal way, according to their practice and experience. On the one hand, P3 described her

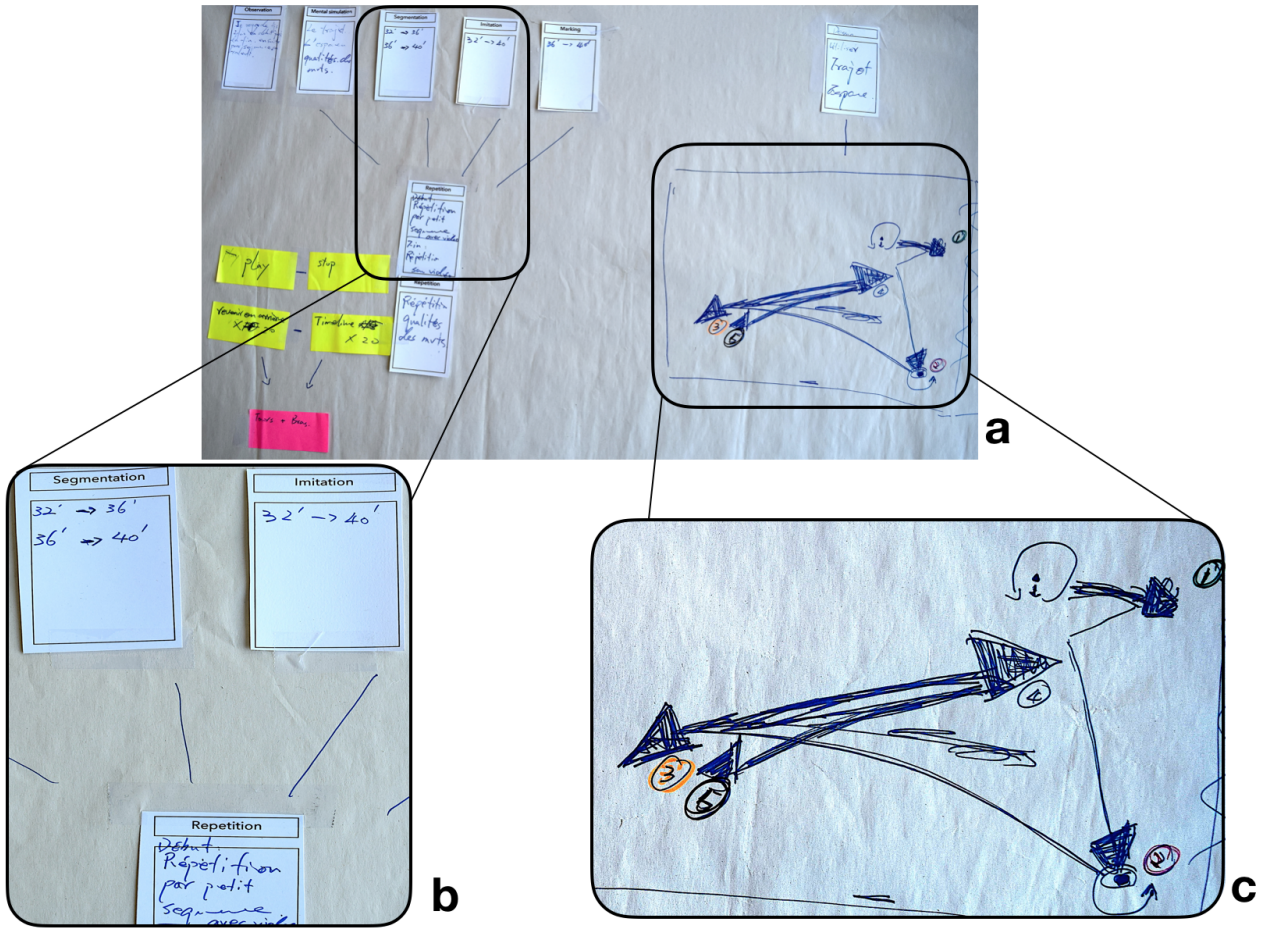


Figure 3.7. P3's composition: (a) Final composition composed of interconnected learning techniques (b) and drawings that show spatial displacements (c).

learning *habits* based on her previous experiences: "*That's why at first I'll do it in more or less the same order. Based on my experience*". P4 and P3 described their compositions as a summary of their usual practice: "*It's a little summary of my habits. When I work on choreography, I create things or learn things*" (P3). Dancers also capture specific difficulties or elements of movement in their segmentation, such as the *quality* and the *trajectory in space* (P3, P2), the *motor of the movement* (P1, P2), and the *energy* (P4). Therefore, how dancers segmented the video has a direct impact on how they structure their learning process.

3.4.3 Video interaction

We observed that their interactions with the video (yellow sticky notes) are linked to the different learning techniques. Observation cards always follow or precede a yellow sticky note that indicates scrolling, playing, or pausing the video. P3 also used a segmentation card to isolate a part that she named *rotation+arms*. She scrolled back this

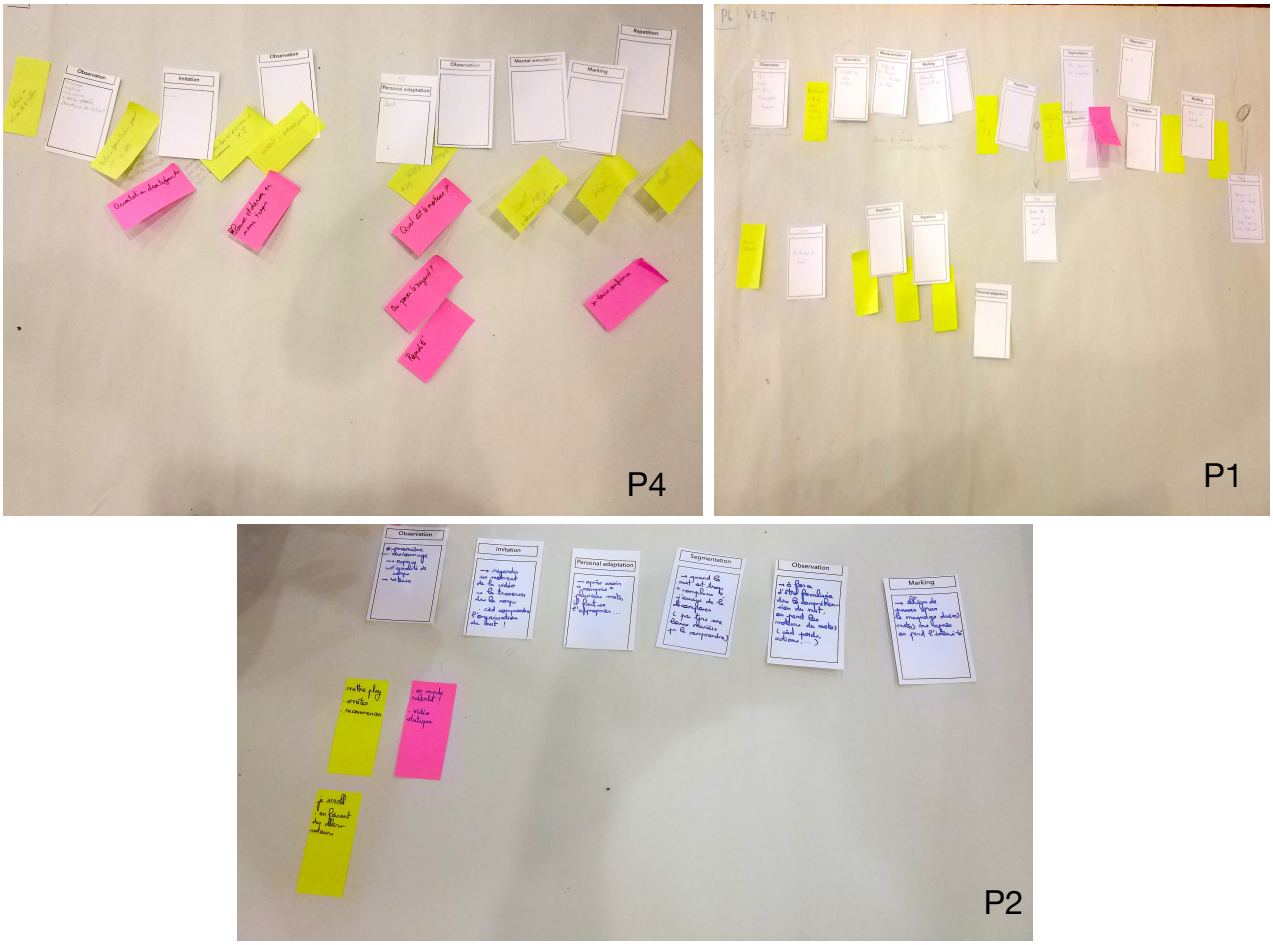


Figure 3.8. The composition realized by P1, P2, and P4. They are all different and personal

movement 20 times to ensure she learned it. The action of scrolling back multiple times is then related to repeating a segmented part of the phrase.

All participants manipulated the progress bar in order to slow down movements: "*I slowed down a lot, to come back, to see the trajectory, the arm, the supports*" (P3). Although dragging the scroll-bar's thumb with the finger does slow the video, P1 and P2 found it jerky and ineffective: "*While scrolling, you don't see energy, you don't see speed, time. And so I missed several periods*" (P2). Slowing down the movement seems linked to the segmentation of the movement and the task's difficulty.

Finally, the dancers were all frustrated by the limitations of the media player, which forced them to interrupt their practice to play, pause or scroll the video: "*I wasn't listening to my body going into space because I was watching the video and not experimenting*" (P1). To avoid the back

and forth between video control and dancing, all of the participants at one point, took the tablet in their hands and practiced the dance while handling it: *"Having a pause button and dancing at the same time is not easy. Sometimes I danced with the tablet in my hand."* (P1).

3.5 Discussion and design implications for tools supporting dance learning

The two studies with contemporary dancers allowed us to understand the practice of dancers at two different levels. Through interviews, I highlighted consistent steps and mechanisms involved in the learning pathways of different dancers and I identified a set of learning techniques used by dancers during their training.In the second study, we used the learning techniques to help dancers reporting on their learning process. With the documentation materials, the dancers were able to report on their learning schedule. In the following, I discuss the benefits and the limitations of the two studies, and I provide four designing implications for tools seeking to support dance learning.

3.5.1 Benefits and limitations of technology-free documentation for dance phrase learning

Contrary to the interviews, the second study was close to dancers' real practice of learning. We show how dancers compose their practice using diverse learning techniques presented on paper. Conducting the second study in an ecological context, a dance studio shared with other dancers, was critical in extracting dancers' behavior consistent with what they exhibit during habitual practice. Though each dancer was following each activity on their own, they were asked to perform the learned phrase after. This realistic social context certainly impacted the way dancers perform the task and inform on their learning strategies. Documentation materials allowed dancers eliciting and discussing each learning technique as a group. Interestingly, this process made the techniques more explicit to the dancers themselves. Kirsh [Kirsh, 2013] argue that to elicit implicit knowledge is may be necessary to use tools or artifacts. We showed that using paper materials allows dancers to articulate a piece of their embodied knowledge.

3.6 Design implications

Based on the results of the two studies, I propose four design implication that support the dance learning processes we observed.

3.6.1 Provide a palette of tools based on learning techniques

Dancers reported a set of actions that they use to facilitate learning across the different phases, i.e. the learning techniques. Dancers choose and combine actions among a "toolkit of techniques". Kirsh [Kirsh, 2013] has shown that marking (execution of a diminished version of the movement) is more efficient than full-out practice and mental simulation when practicing technique and timing. However, imitation can provide more completeness. Therefore interactive systems should provide a toolkit allowing dancers to choose among several interactive tools according to their goal, as well as their preferences. A successful learning system should cover a combination of interactive tools supporting specific techniques. I argue that learning techniques provide an initial set of tools that can be transformed into interactive objects to support dance learning. For example, based on the learning technique *repetition*, dancers should be able to repeat part of a video multiple times. Dancers should also have the opportunity to combine several learning techniques together.

3.6.2 Save a tangible trace of the learning process

The dancers were able to use documentation materials to report and produce a trace of their learning process. Each dancer's composition is a tangible trace that support dancers reflect and explain their actions and problems with the video. I argue that a technology designed to support dance learning should support dancers in creating a tangible trace of their learning process, like an "interactive composition". Dancers should be able to choose from a variety of interactive tools and organize them as they learn with the technology. The trace should be interactive. It signifies that dancers should be able to "replay" what happened during their learning process. This trace could be recorded and analyzed by computer tools, allowing a more in-depth analysis and comparison between dancers. I argue that an interactive trace of the learning process would also support dancers in explaining and articulate their learning process and embodied knowledge.

3.6.3 Extract implicit movement variations and make them explicit

We found that dancers apply implicit and explicit variations to execute and appropriate movements. I argue that current systems aiming at supporting dance skill acquisition should treat these variations not as noise but as an essential learning component. Some existing systems in HCI that rely on pattern matching ignore variations and consider it to noise or error. However, few current research proposed another approach where variations of movement execution are taken into consideration with the specific goal of augmenting the expressive bandwidth of interaction techniques. Caramiaux et al. [2015b] proposed a machine learning-based system able to recognize gestures in realtime and, in parallel, track spatial and dynamical gesture variations. This technique has been used in various applications such as sonic interaction design or virtual archeology. Another example is the "expressive keyboards " [Alvina et al., 2016], a system for smartphones that maps variation on input gesture in an attempt to enrich the output text.

3.6.4 Support personalization of learned movement

I highlight three main phases in the learning process, the analysis phase, the integration phase and the appropriation phase. Systems supporting motor skill learning tend to act on the analysis phase by providing tools to comprehend the movement to realize, i.e. the reference movement. Such systems are bound to the analysis phase and do not consider the integration of the movement nor its appropriation. I argue that in dance, the appropriation phase is an inherent part of the learning process and should therefore be addressed. This means that a system should support dancers appropriating movements and allows them to apply expressive qualities. Therefore it should be accounted for in designing for motor skill learning.

3.7 Chapter Summary

I interviewed 11 contemporary dancers about their learning practices and identified different steps in dancers' learning progression as well as a set of learning techniques. Based on these insights, I conducted a participatory workshop with four dancers where they reported on their progression with documentation materials. This resulted in a tangible trace of the learning schedule, where we highlighted the structuring role of the segmentation during learning. These two studies, combining interviews, technology-free documentation, and group dis-

cussion, bring many details on dancers' learning practice. Finally, we propose four design implications for the design of technological systems supporting dance learning. However, one limitation is that the dancers could not further explain the segmentation process either during interviews or with their composition. In the next section, we introduce the design of a technology probe based on implications for design presented in this chapter. This technology supports the dancers' segmentation process by making it interactive and allows dancers to save an interactive trace of their learning.

3.7.1 Contributions

- Description of dancers' learning techniques including observation, imitation, marking, mental simulation, segmentation, personal adaptation, repetition, and segmentation of movements.

- Investigation of learning techniques and documentation materials to support dancers in saving a trace of their learning process and understand the actions and issues related to current video media players.

- Identification of the video segmentation process as an embodied knowledge that structures dancers' learning.

- Implication for the design of tools to support and understand embodied knowledge: Save a tangible trace of the learning process, Provide a palette of tools based on learning techniques, Extract implicit movement variations and make them explicit, and Support personalization of learned movement.

4

Capturing and Reifying the Segmentation Process

This chapter introduces MoveOn*, a web-based technology probe designed to segment dance video into short, repeatable clips, and saves a trace of this segmentation over time. I describe a technology probe study with six dancers using* MoveOn *in a dance learning task. Finally, I discuss how* MoveOn *serves as an effective analysis tool to understand and support the segmentation process and facilitate dance learning.*

This chapter includes written material published in [Rivière et al., 2019] [1]*. This paper was a collaborative effort conducted with Sarah Fdili Alaoui, Baptiste Caramiaux, and Wendy Mackay. I was the lead and corresponding author on this paper.*

[1] Jean-Philippe Rivière, Sarah Alaoui, Baptiste Caramiaux, Wendy Mackay. Capturing Movement Decomposition to Support Learning and Teaching in Contemporary Dance. *Proceedings of the ACM on Human-Computer Interaction , Association for Computing Machinery (ACM), 2019, Proceedings of the ACM on Human-Computer Interaction, 3 (CSCW), pp.1-22.* 10.1145/3359188ff. hal-02378487f

The results of the Chapter 3 show that dancers can report on their learning process with documentation materials. We showed that dancers are able to explain their learning process using their composition and highlight that dancers structured their learning process by segmenting the choreography and repeating "chunks" of videos. However, technology-free documentation and group discussion did not bring more details on how dancers segmented the choreography during learning.

Previous work emphasized the importance of segmentation for motor learning [Swallow et al., 2009, Sargent et al., 2013], especially in dance, where the segmentation process is directly related to memory

and expertise [Bläsing, 2015]. Examining how dancers segment dance phrase is an important question to understand how dancers structure their learning process. Following the design implications presented in Chapter 3, I designed an interactive system to advance our understanding of video segmentation.

This chapter presents the design of *MoveOn*. I employed *MoveOn* as a technology probe in a study conducted with six contemporary dancers to understand and support dancers' behavior of video segmentation.

4.1 *MoveOn*: a tool to reify movemement segmentation

Inspired by the results of Chapter 3, I wanted to support and push further the understanding of how dancers segment dance video while learning. I created *MoveOn*, a technology probe with the goal of supporting and capturing the process of video segmentation. A technology probe is a simple, flexible, and adaptable technology usually deployed in real-world situations. *MoveOn* has three goals, a social goal of collecting data about video segmentation, an engineering goal of testing the technology with dancers on the field, and a design goal of inspiring novel design ideas with the dancers.

MoveOn is a website embedding a classic media player (Fig. 4.1), where a user can load videos from different sources, e.g. Youtube, Vimeo. I deliberately simplified the video's functionalities compared to a regular media player to reduce the possible interactions. The media player allows users to play, pause, and navigate in the video. In addition to this, *MoveOn* allows the creation of segments of dance video. These segments save a trace of the segmentation process over time. In the following sections, I elaborate on the two main features of *MoveOn*. The source code of *MoveOn* is available at the following address: `https://github.com/Jean-py/Moveon`

4.1.1 Decomposing video into segments

The main feature of *MoveOn* is the possibility to create segments. A segment is an interactive annotation associated with a specific part of a video. For each segment, a user can define a number of repetitions, a speed, and a text annotation. When the user touches a segment, the segment "plays". It signifies that the related part of the video is played the specified number of times at the defined speed. Figure 4.2 depicts the visual aspect and the properties of a segment.

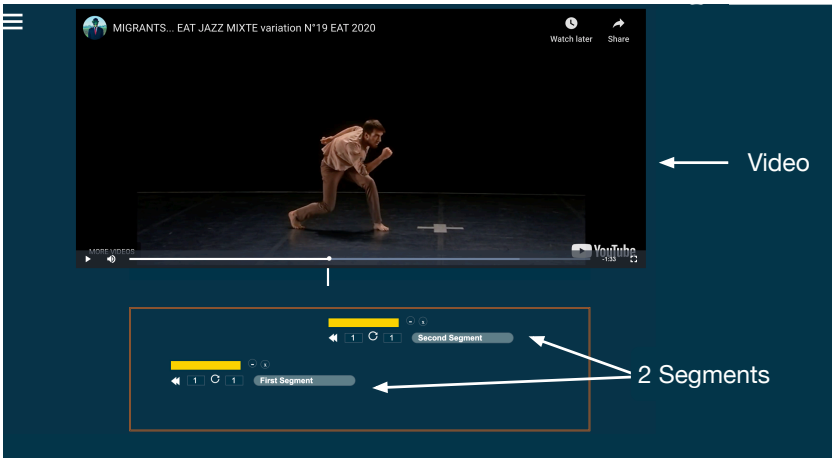


Figure 4.1. ***MoveOn*** **interface.**

To create a segment, the user defines the starting point and the ending point of the segment. This is depicted in Figure 4.3. To create a segment, the user needs to press on the white bar below the scroll-bar. A segment appears below the scroll-bar bar (see Figure 4.3a). The user can navigate into the video (see Figure 4.3b). A segment is created when the user taps on the yellow bar below the video (see Figure 4.3c). Once created, the segments appear under the video.

Following the design implication, "Provide a palette of tools based on learning techniques", a segment allows the user to engage in the segmentation and repetition of a specific part of the video. The visual representation of a segment embeds two properties: its starting point in the video (represented by its left margin) and its duration (represented by its length).

4.1.2 Tracing segmentation through segment history

The second goal of *MoveOn* is to save an interactive trace of the segmentation over time. The technology probe saves all the segments created by a user in a *segment history*. A segment history is a time-ordered stack of the different segments created by the user. A newly created segment is placed at the top of the *segment history*, so the first segment created is always at the bottom.

Following the implication for design "Save a tangible trace of the learning process", the segment history trace the dancers' segmentation over time. It is meant to enable the dancers to design and reflect on their learning process and for the researchers to analyze and understand the dancers' segmentation strategies. The Figure 4.4 shows the interface of

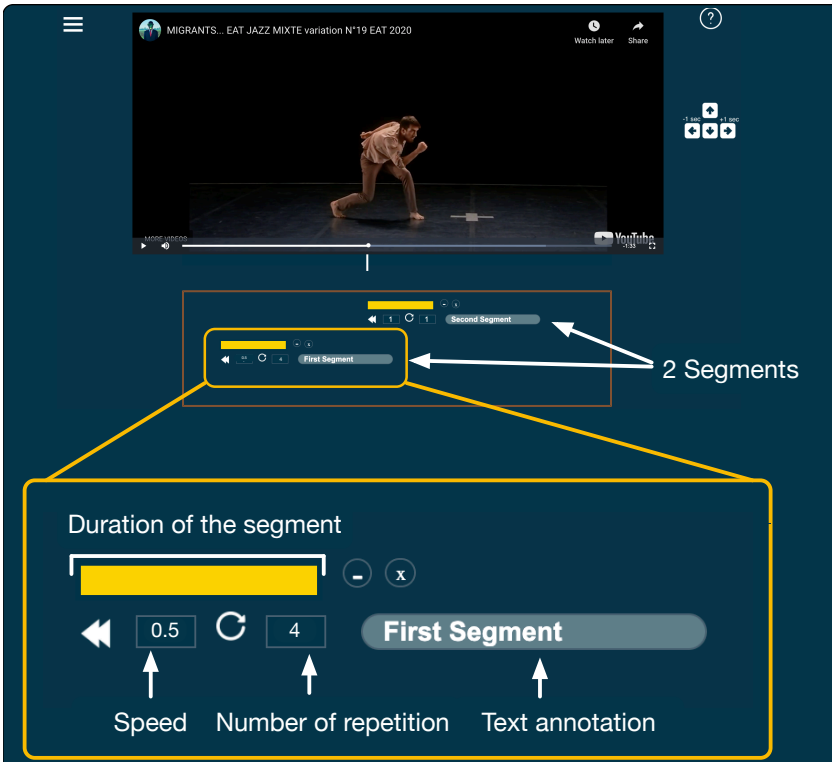
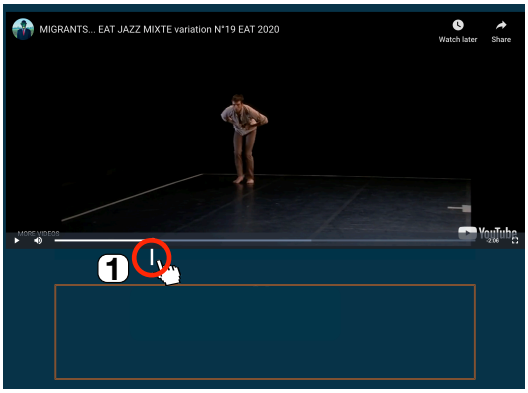
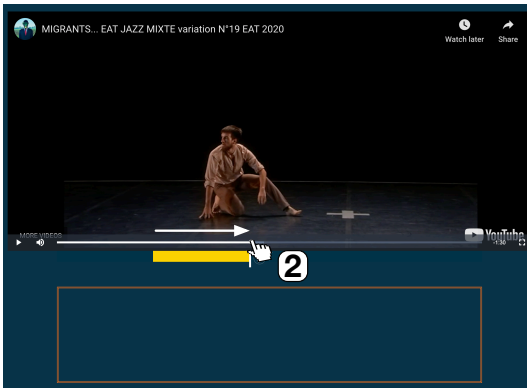


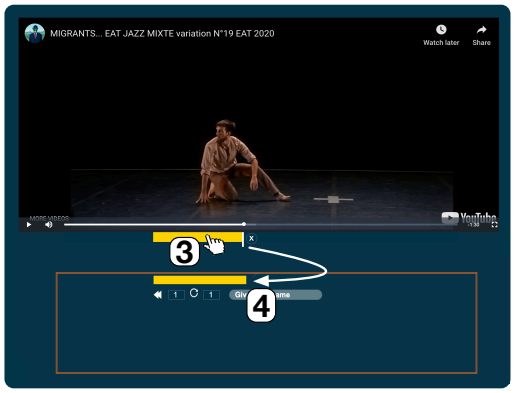
Figure 4.2. A segment corresponds to a defined video part and embeds three properties: speed, number of repetitions and text annotation. Clicking on a segment plays the related video part the specified number of times at the defined speed.



Starting the creation of a segment



Defining the duration of a segment



Completing the creation of a segment

Figure 4.3. Three steps to create a segment: (1) The user defines a new segment's starting point by tapping the white bar below the scroll bar's thumbs. (2) The user navigates in the video with the media player. (3) The user defines the segment's ending point by tapping the white bar. (4) A new segment is created in the segment history below the video. When the user touches the segment, the player repeats the corresponding video fragment (from start to end

MoveOn: There are three segments created, grouped in the "Segment History" box.

4.1.3 Implementation

I created a web server in Node.js with an embedded video media player. The web server allows for portability among several platforms: tablet for participants and a laptop for coding and debugging. I implemented a save-and-load function of the segment history to save and analyze each participant's segment history after the session. An action logger saves the actions performed on the website in a JSON file. A JSON file (JavaScript Object Notation) is a text file that can be stored in any computer and load into *MoveOn*. *MoveOn* log actions of the users: navigating in the video, creating a segment, playing or pausing a segment, changing the speed and the number of repetitions of each segment. I chose to log these actions to be able to reconstruct and study the actions performed by the dancers.

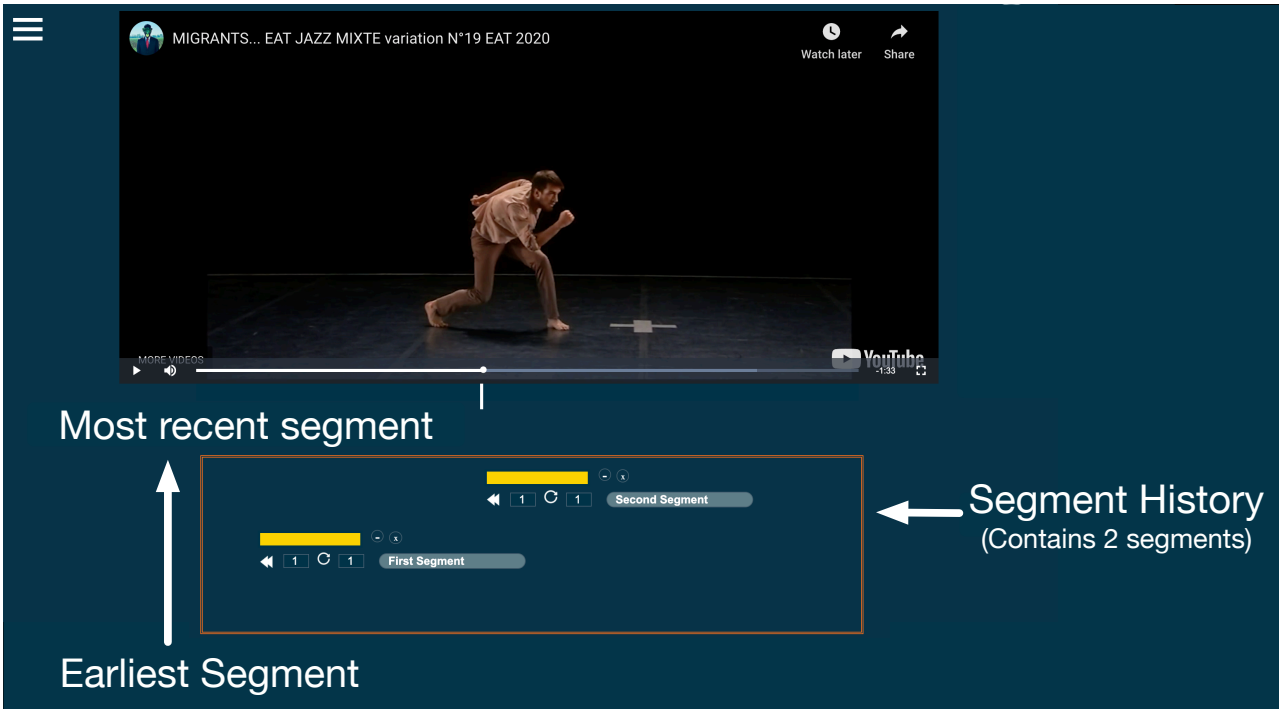


Figure 4.4. ***MoveOn*** **displays a video, and a segment history containing two segments (in yellow). The segments' history is read from bottom to top. The top segment is the most recent and the bottom segment the earliest. The length of a segment corresponds to its duration and the left margin to its position on the video. Clicking on a segment plays the corresponding part of the video.**

4.2 Study 3: Capturing the segmentation process

My supervisors and I conducted a technology probe study to investigate the use of *MoveOn* by dancers in a real dance learning task. *MoveOn* allows the dancers to segment and repeat part of the video while learning. While dancers used *MoveOn* as a learning support tool, We saw it as an analytical tool for gathering information about

how dancer segment movements.

4.2.1 Method

4.2.1.1 Participants

We recruited 6 experienced contemporary dancers (5 women, 1 man) with 6 to 30 years of experience. The participants were recruited from our contacts and were not compensated but were invited for lunch before the session. All participants had previous experience learning dance from videos. Two of the six participants also participated in the second study of Chapter 3.

4.2.1.2 Setup

We ran the session in a local dance studio. The session lasted approximately two hours. All participants agreed to participate in the study and signed a consent form validated by an ethics committee. Each participant was given a tablet[2] with *MoveOn* installed and running, presenting the user with the same video used in the study two (see Section 3.3). Two laptops [3] were used as servers to host the websites.

[2] iPad apple iOS 6 version 10.3.3, screen 9.7 2048 x 1536, 14G6

[3] MacBook Pro-macOS High Sierra, 13 inches, SSD 256Go, processor 2,3 GHz Intel Core i5, RAM 16Go, and MSI GS60-Windows 7, 15 inches, processor 2,6 GHz Intel Core i5, RAM 8Go

4.2.1.3 Procedure

We welcomed the participants to the studio and presented the general objective of our study. We described the task that consisted of learning the video-recorded dance excerpt using *MoveOn*. We distributed the tablets and explained to the participants how to start and stop the video, create segments, and interact with the segment history (Fig.4.5). We encouraged them to create multiple segments and did not provide further instructions about when and why creating segments. Once the technology was demonstrated, we gave the participants 45 minutes to learn the dance clip. We then asked each participant to perform what they learned from the clip. Finally, we sat all together and asked each participant to explain their segment history. We engaged in a group discussion on the action of segmenting, the difficulty of the task, and the opportunities and problems perceived.

4.2.1.4 Data collection and analysis

We documented the sessions through video recordings and photographs. We also logged all the segments created by the participants. The load function implemented in *MoveOn* (but not exposed to the participants) allowed us to visualize the complete segment histories, including deleted segments. This allowed qualitative comparison of the strategies of each participant. One researcher analyzed participants' segments and segment histories and compared them with each other, looking for similar patterns. The recording of the group discussion

was analyzed using thematic analysis following [Guest et al., 2011]. We revised the results of the coding and constructed three themes: *Movement segmentation strategy*, *Foci behind segment creation*, and *Transmission and reuse*. In the following section, we anonymized the data and refer to the dancers as participants 1 to 6, denoted P1 – P6.

Figure 4.5. The six dancers practicing with *MoveOn*.

4.2.2 Results

4.2.2.1 The use of the technology and the tablet

All participants created a segment history that included from 4 segments (P1-P2) to 8 segments (P3, P5, P6) (Fig.4.7, 4.8, and 4.9). P4 was the only one that created several segments before dancing, while the other participants created segments when they needed them. All participants at one point tried to hold the tablet in their hand (see Fig.4.6) and dance but they expressed that with the tablet, they felt constrain and could only mark the movement. Furthermore, P4 expressed that "*it immobilized the arm holding the tablet*". Instead, they alternated between interacting with the tablet in their hands (Fig.4.6) or placing it on the floor so they could play the segments and dance at the same time, with or without looking at the screen.

4.2.2.2 Movement segmentation strategy

We identified two strategies when creating multiple segments: the *regrouping* and *ungrouping* strategy. On the one hand, regrouping corresponds to the creation of a new segment from multiple previously-created segments. P3 and P6 reported that they created segments that

encompass several smaller segments. For example, P6 stated "*I wanted to make a third one that includes the first two segments. To create a sequence, I created another one that included both*". On the other hand, ungrouping correspond to exposing smaller chunks within a larger sequence. For instance, P6 started by creating a large segment and then dividing it into multiple smaller chunks: "*I just make and forget the rest. Inside, if I perceived a strategic point, I would put back a little segment*".

Regrouping and ungrouping strategies shed light on the ways in which the participants chose to handle segment transitions. The participants overlapped each segment with adjacent ones and repeated the transitions between each segment every time. P5 raised the possibility that *MoveOn* could be pro-active in handling segment transitions: "*When you create a segment, it would be nice if it were directly at the end of the next one*". Additionally, P6 raised a concern about a problem that could arrive from creating independent segments: "*Between two dance sequences, there was some information I missed. Because it was neither in the end of one [segment] nor the beginning of the other*".

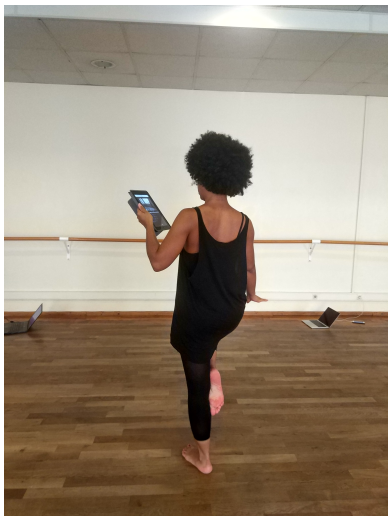


Figure 4.6: P4 holding the tablet in her hand while dancing.

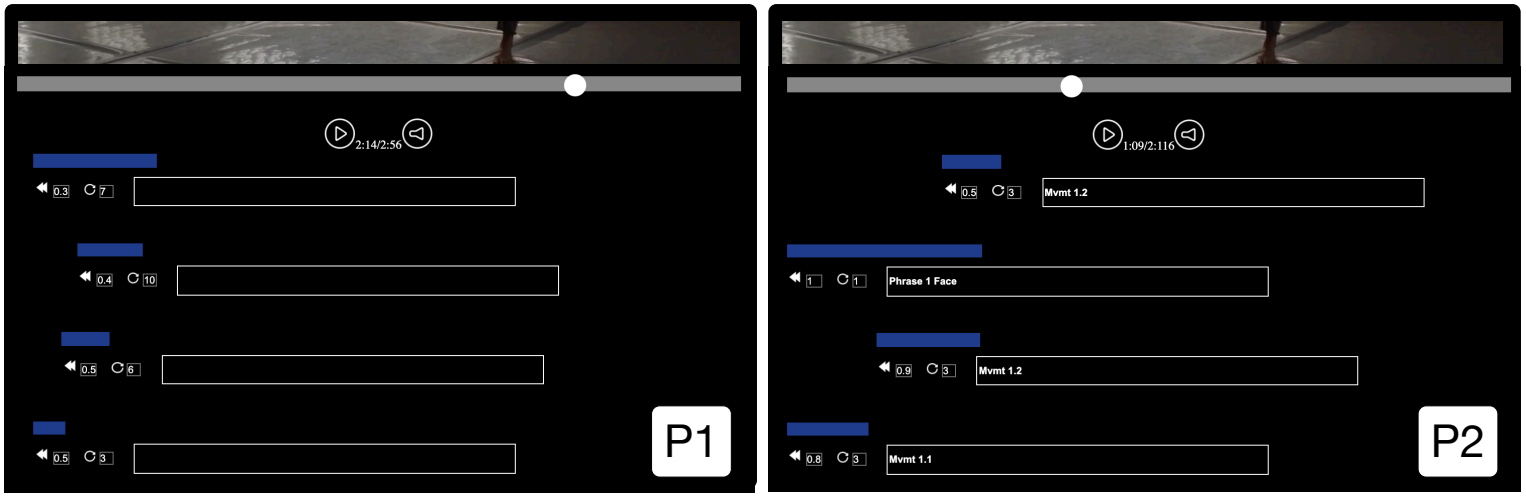


Figure 4.7. P1's and P2's segmentation. (Screenshot produced from an old version of *MoveOn*)

4.2.2.3 *Foci behind segment creation*

Participants created segments according to various needs, especially when dance content was too difficult or based on their personal interest surrounding a section of video content. P5 used segments to repeat part of the video and slowed it down in order to unravel the movement: "*[Slow motion] helped me a lot looking at the details*". P5 stated that the more rotation or speeds there were, the more she repeated or slowed down the movement. For P1, segmenting helped her figure out the "*starting point of the movement*" and to reproduce the difficult

movements.

We also identified various movement foci that drove the segmentation process. Movements were segmented based on changes in characteristics such as *space* or the *the starting point of the movement*. For example, P5 segmented the phrase according to the spatial orientation: "*The first sentence was because we were in front, I cut like this for the orientations*".

Figure 4.8. P3's and P4's segmentation. (Screenshot produced from an old version of *MoveOn*)

4.2.2.4 *Transmission and reuse*

The discussion made participants suggest the potential of the technology to be used in movement transmission and pedagogy. P6 stated that segment histories are a way to "*see the different approaches of people's segmentation*". P6 would also like to see different annotation approaches: "*It would be interesting to suggest some possibilities. Different ways, different annotation schemes*". P5 suggested that beyond a personal context, *MoveOn* could be used for transmission: "*Beyond memorization, I find it interesting for transmission. When I give a lesson, I film myself and I have to transmit it. It helps me get ready. How I am going to transmit it.*" She emphasized the potential of reusing one's composition: "*when it is my movement, it is interesting to be able to say to the others, "I would like you to try to learn it this way, with this sequence"*". Additionally, P5 mentioned *MoveOn*'s ability to share people's foci in dance: "*We also have*

the concept of the person, on what he or she focuses on. That means what was important for him or her".

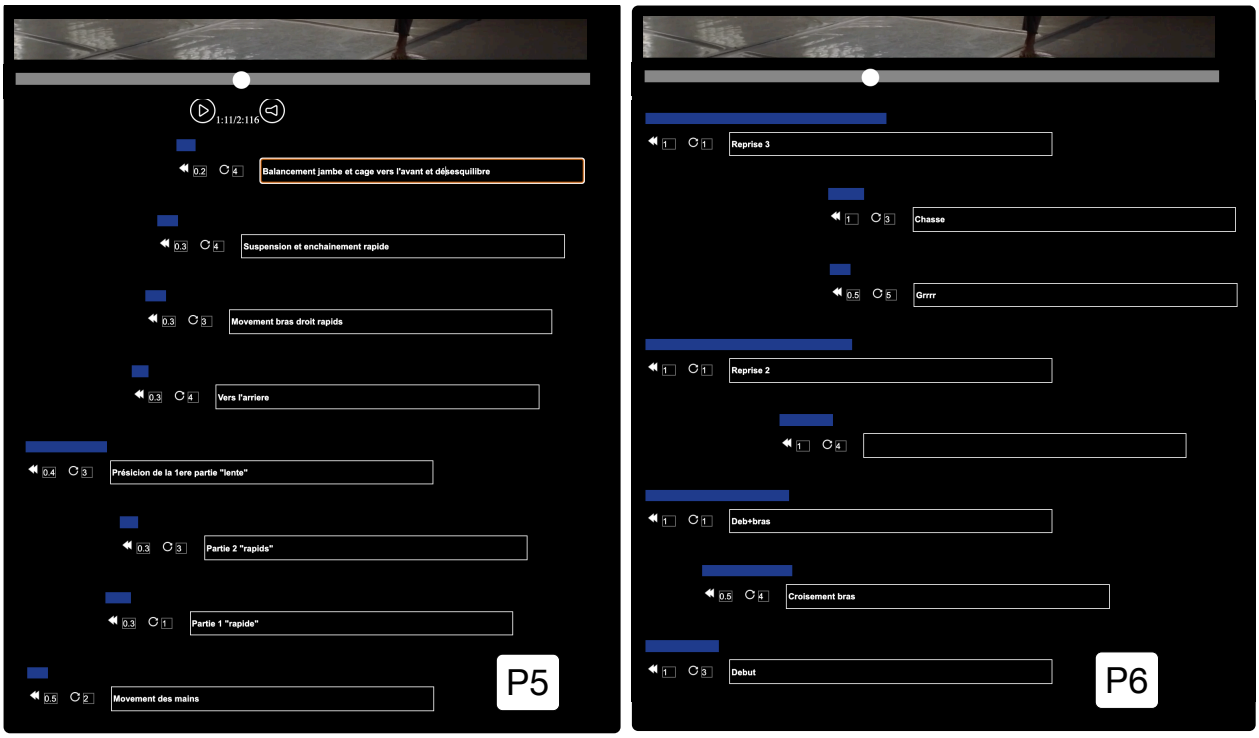


Figure 4.9. P5's and P6's segmentation. (Screenshot produced from an old version of *MoveOn*)

4.3 Discussion

4.3.1 Movement segmentation using *MoveOn* as a lense

The design of *MoveOn* was inspired by the concept of reification introduced in HCI by Beaudouin-Lafon and Mackay [Beaudouin-Lafon and Mackay, 2000]. The process of reification is defined as "the process by which concepts are turned into objects". I used the reification principle to transform dancers' learning techniques (e.g. repetition, segmentation, movement foci among others) into concrete interactive objects. In *MoveOn*, a segment of video reifies the concept of segmenting and repeating a chunk of the dance choreography at a certain speed, several times. Through reification, I give the user more agency via the possibility of manipulating concrete visible tools that embody their practice. This also allows us to reveal and visually render the user's habitual methods. By making it interactive, I open opportunities for new methods and know-how to emerge.

The use of the tool by the dancers made decomposition strategies

apparent. In other words, the segment history made the learning schemes adopted by each dancer more tangible. Interestingly, we found distinguishable patterns in dancers how dancers decompose and recompose the video. There seems to be consistency in the way dancers decompose a dance phrase in relation to where the segments are placed, in which order, as well as how segments are combined or divided.

While the amount of data collected in our study is too limited to further analyze those patterns, the fact that a tendency can already be observed with a limited number of dancers is promising. Further research would benefit from a larger sample of dancers by deploying the system more widely. This would certainly bring new insights on movement decomposition, beyond strategies found in this paper and consequently advance the knowledge in more theoretical aspects of motor learning such as *chunking*, which is the decomposition of sequences of movements into strongly associated sub-segments [Diedrichsen and Kornysheva, 2015, Gobet et al., 2001].

4.3.2 Sharing video segmentation with *MoveOn*

During the group discussion, the participants pointed out the potential of *MoveOn* as a transmission tool. The dancers wanted to know to what extent a segment history can be shared across dancers. This is an interesting question with implications for cognitive science and dance education.

In fact, designing and providing learning schemes is a fundamental problem in pedagogy. Several works addressed this problem by looking at the ways to schedule tasks and their variations to optimize practice [Shea and Morgan, 1979]. Different strategies are tested in various cases such as continuous pursuit tracking, [Wulf and Schmidt, 1997], sport practice [Travlos, 2010], or music [Caramiaux et al., 2018], with varying results according to the field of application. *MoveOn* has the potential to serve as a medium between the teacher and dancers for example in distributed or remote learning. It may also provide new perspectives on analyzing learning schedules and extracting prototypical learning schemes.

4.4 Chapter summary

I designed *MoveOn* as a video-based tool to support dancers' learning through segmenting and repeating dance videos. Specifically, *MoveOn* allows users to watch, segment, repeat, and play video clips. I deployed *MoveOn* in a technology probe study with six contemporary dancers, learning a choreography from a video. In this study, *MoveOn* serves as an effective analysis tool for identifying the changes in focus and understanding segmentation and recomposition strategies.

During the group discussion, the dancers raised the possibility to share their segment history for learning dance. This idea drives the design of a follow-up study with *MoveOn*, where we look at how segment histories can be shared and reused to support dance learning.

4.4.1 Contributions

- Implementation of *MoveOn*, a technology probe that lets dancers segment video into short, repeatable clips to support their learning.
  - Reification of users' segmentation into interaction techniques. A segment allows dancers to engage in the segmentation and repetition of a specific part of the video.
  - Implementation of the segment history, an ordered stack of segments. The segment history provides an interactive trace of the segmentation process. It serves as an effective analysis tool to identify the changes in focus and understand the segmentation pattern. It allows dancers to reflect on their segmentation more precisely than interviews and observations.
- Identification of two strategies of segmentation: ungrouping and regrouping segments. Dancers *regroup* a set of segments into a larger one to focus on the big picture and transition. Dancers *ungroup* large segments into shorter ones to focus on details and problems.

5

Sharing and Reusing Video Segmentation

This chapter presents a structured observation with one teacher and six dancers to examine the possibility of sharing segment history. I compared how dancers learn on their own to a teacher-created segmentation. The results suggest that teacher-created segmentation is more effective for novice students, whereas personal segmentation is more suitable for expert dancers.

This chapter includes written material published in [Rivière et al., 2019] [1]*. This paper was a collaborative effort conducted with Sarah Fdili Alaoui, Baptiste Caramiaux, and Wendy Mackay.*

I showed how dancers segment movement during their progression and recompose them to form phrases in Chapter 4. The segmentation history reveals the segmentation process and allows dancers to reflect on their learning process. During the group discussion, the dancers identified the opportunity of sharing their segmentation for educational purposes.

Inspired by this concept of sharing and reusing segmentation for educational purposes, we explore the use of *MoveOn* to teach dance and examine how a pre-defined segment history can affect dancers' learning practice. The literature on the effect of learning schedule on motor skill acquisition also inspired this study. Previous studies show that the way learners practice and train, i.e. the schedule of practice, greatly influence the retention and the performance of a motor

[1] Jean-Philippe Rivière, Sarah Alaoui, Baptiste Caramiaux, Wendy Mackay. Capturing Movement Decomposition to Support Learning and Teaching in Contemporary Dance. *Proceedings of the ACM on Human-Computer Interaction , Association for Computing Machinery (ACM), 2019, Proceedings of the ACM on Human-Computer Interaction, 3 (CSCW), pp.1-22.* 10.1145/3359188ff. hal-02378487f

skill [Magill and Hall, 1990]. In particular, the way novice learners implement their practice has a substantial impact on skill retention [Hebert et al., 1996]. Researchers studied the impact of learning practices on movement retention by proposing different learning methods. For example, researchers decomposed long movement into meaningful 'units' and test the effect of blocked practice (a single unit is repeated over and over before moving on to a second unit), over random or self-scheduled practice.

This chapter presents a structured observation where I use *MoveOn* to 1) compare teacher's and dancers' segmentation strategies, and 2) compare the effect of a self-created versus a teacher-created segmentation on students' learning. I discuss the challenges underlying this approach, as well as its limitations. Then, I discuss the dance studio's social and collaborative nature and its implication when designing for dance learning.

5.1 Method

5.1.1 Design

My supervisors and I conducted a qualitative inquiry of the impact of two segmentation strategies on learning a dance phrase from a video recording. The study followed a within-subjects design in which each participant experienced two cases, segmenting the movement or following a pre-defined segmentation:

- The **dancer segmentation** case in which dance students learn a dance phrase using their own self-created segmentation on the tool.

- The **teacher segmentation** case where dance students learn a dance phrase using a video segmentation previously created by a teacher.

5.1.2 Participants: dancers and teacher

We collaborated with a contemporary dance teacher from our university, with 40 years of dance experience and teaching. She teaches a contemporary dance class every week for 4 hours with 6 students. These 6 students are the 6 participants in this study. On average, the participants dance 4h per week and practiced contemporary dance for 6 years. There are 5 female dancers and 1 male dancer, ranging from 22 to 42 years old. None of the participants were involved in previous studies.

5.1.3 Videos and teacher segmentation

Before the study, we asked the teacher to choose two video clips of contemporary dance. We explicitly asked her to choose videos that her students had never seen before, with equivalent difficulty levels. The teacher chose two dance videos from the EAT (the national dance exam) that she clipped to be of equivalent length. The videos last 43 and 47 seconds, respectively. Both videos are snippets of contemporary dance solos performed by professional dancers. These two videos vary in difficulty regarding movement variations, variations in space, rotation, change of balance, falling, and weights shifts. The original links of the two video are in footnotes [2].

[2] Video 1: : https://www.numeridanse.tv/videotheque-danse/epreuves-de-danse-2015-danse-contemporaine-variati

Video 2: https://www.numeridanse.tv/videotheque-danse/epreuves-de-danse-2015-danse-ccontemporaine-variat

For each video, the teacher created a segmentation of the dance phrase with the probe. We instructed the teacher to: *"Segment the video as you would teach it to your student. You can annotate segments, change the number of repetitions and the speed. Remember that your student will have to strictly follow your segmentation to learn the dance phrase"*. We did not limit the time taken by the teacher to create the segmentation; she was free to explore and converge towards the most "pedagogic" segmentation. She took approximately 4 hours to create the two segmentations (2 hours each).

5.1.4 Setup and procedure

We ran the session in a dance studio. The session lasted approximately 150 mins. We gave an iPad tablet[3] to each participant on which the tool was running on a web browser. Two laptops [4] were brought in the dance studio and used as servers to host a local version of *MoveOn* handling the video and logging.

[3] iPad apple iOS 6 version 10.3.3, screen 9.7 2048 x 1536, 14G6

[4] MacBook Pro-macOS High Sierra, 13 inches, SSD 256Go, processor 2,3 GHz Intel Core i5, RAM 16Go MSI GS60-Windows 7, 15 inches, processor 2,6 GHz Intel Core i5, RAM 8Go

Before the beginning of the study, all participants agreed to participate in the study and signed a consent form validated by an ethics committee. We did not compensate the participants for their participation. Two members of our research lab attended the session to help with the setup and filming.

The dancers started by warming up for approximately 30 minutes under the supervision of the teacher. Then we distributed the tablets and explained to the participants the use of the tool: how to start and stop the video, how to create a segment, and how to interact with segments, i.e. clicking on the segment to play it, changing the number of repetitions, its playback speed and adding a label.

In the first activity, we split the 6 dancers into 2 groups of 3 in a ran-

dom manner (Fig.5.1, 5.2). We asked all the participants to learn the first dance video using *MoveOn* on the tablet. The dancers of the first group were free to learn and segment on their own with the probe. We encouraged them to create multiple segments; however, we did not give them instructions about when or why creating a segment. We instructed the second group of dancers to follow the teacher's segmentation displayed on the probe. For this group, the instructions were: *"Your goal is to learn the dance phrase on the video using the segmentation presented to you. You will start with the first segment (the one at the bottom) and play them one by one. You must let the segment play the number of times specified. When you finished following a segment, you can either continue to play it again or move on to the next segment."*

Figure 5.1. The dancers of group 1 following the teacher-segmentation.

Both groups had 30 minutes to accomplish this task. Afterward, we asked each participant to perform what they learned. We took a 10 minutes break to save each segment history and prepare the second activity.

In the second activity, we reversed the role with video 2. The first group followed the segmentation created by the teacher, while the second group learned the dance phrase and created their own segmentation.

After 30 minutes, we asked each participant to dance what they learned from the second video. After each performance, we distributed the same Likert scale questionnaire to the participants to evaluate their experience of the study. This questionnaire inquired:

Figure 5.2. The dancers of the group 2 learning on their own.

- satisfaction during the activity,
- their level of confidence in the acquisition of the phrase,
- their satisfaction over their performance,
- the usefulness of the features (repeat, segment, slowdown, annotate), and
- the helpfulness of the tool to analyze and understand the phrase and the practice.

Finally, in a group discussion, we asked each participant to reflect on and explain their segment history (Fig. 5.4a). We engaged in a dialogue on the differences between following an imposed segmentation versus creating their own, the difficulty of the task, and the opportunities and problems perceived (Fig.5.3b).

After the study, we interviewed the teacher and asked her to explain her two segmentation step by step and evaluate the dancers' performance. She reviewed their performances based on the captured videos of the session. She watched each performance and gave them a score from 1 to 10.

5.1.5 Data collection and analysis

We documented the session through video recordings and photographs. We saved all the segment histories and logged all the actions performed by the participants (play, pause, navigating in the video with the progress bar, creating or modifying segments). We linked each

Figure 5.3. Overview of the group discussion.

Figure 5.4. A dancer presenting her segment history to the group during the group discussion.

participant's segment history to their explanation and to the teacher's grade.We evaluated the dancers' experience through the Likert scale questionnaire and the statements made during the debriefing. We analyzed the round table, discussion, and debriefing using thematic analysis [Guest et al., 2011]. In the following, we will refer to the dancers as participants 1 to 6 denoted $P1$ – $P6$ and to the teacher as TC

5.1.6 Results

5.1.6.1 Segmentation and strategies

In both teacher and dancers' segmentations, we found the same two strategies highlighted in the Chapter 4 (see Section 4.2.2.2). More precisely, dancers and teacher segmented the movement by creating 2 to 3 shorter segments (that we called the *ungroup strategy*) and then reassemble these segments into longer phrases (*regroup strategy*).

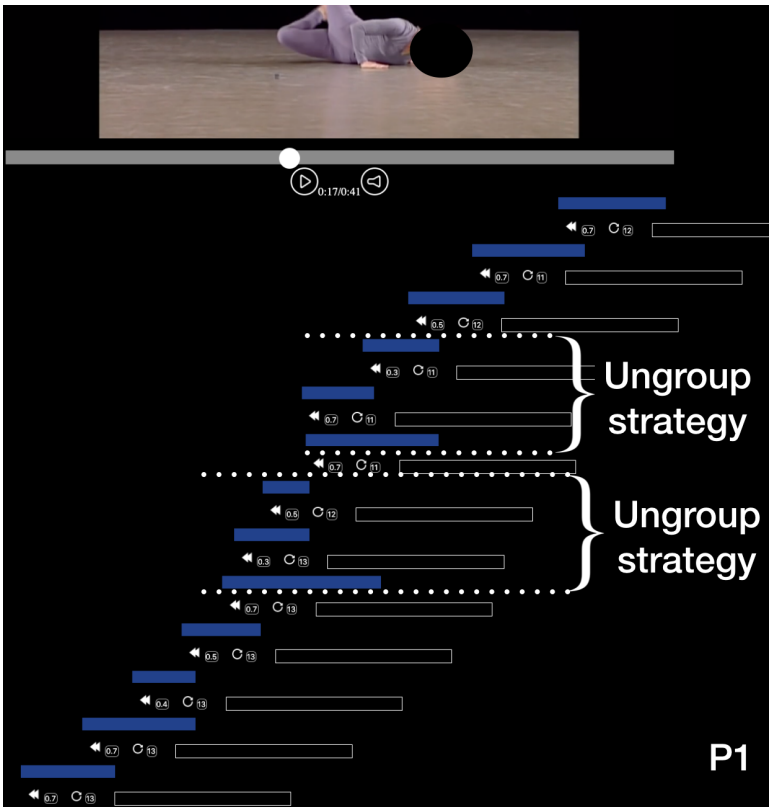


Figure 5.5. P1's segmentation contains 13 overlapping segments. P1 used the ungroup strategy to exposes smaller chunks within a larger sequence. (Screenshot produced from an old version of *MoveOn*)

On managing the transition between neighboring movements, we found that a newly created segment is almost always overlapping with the previous one created in both dancers or teacher segmentation. The two teacher's segmentations present 92% and 95% of overlapping segments with the previous neighbor. In dancers' segmentation, 4 dancers out of 5 generated more than 80% of overlapping segments. Fig. 5.5 and Fig. 5.7, that represent respectively P1 and P2's segmentation, depict examples of overlapping segments. The only exception is P3's segmentation, where we can distinctly cluster four sets of segments that do not overlap. It seems that P3 worked on four distinct parts of the video without focusing on transitions. Interestingly, P3 did not succeed in performing the dance when using her personal segmentation. This could be partly due to the fact that she did not include

transitions in her segmentation.

5.1.6.2 *Different drives between segmentation for learning and transmission*

Video segmentation varies between dancers and the teacher. Dancers created video segmentation to learn the dance phrase in a limited amount of time. TC created video segmentation to transmit the dance phrase to the student in the best possible way.

Regarding dancer segmentation, we confirmed certain foci used by the dancers and highlighted in Chapter 4. Foci that drive dancers' segmentation are mostly space and spatial orientation, completed with personal and idiosyncratic ones. All the dancers started segmenting from the beginning of the video, in chronological order. Most of the participants (4/5) segmented the video according to the orientation of the movement in the scene (P2, P3, P4, P5). P2 segmented in that way to: "*visualize and to know where I am going in space. Once I know the direction, I can work on details*". P5 also explained segmenting according to the dancer's static and dynamic movements. Interestingly, P1 chose to segment regardless of specific foci and created segments of equal duration (around 5 seconds). P1 explained that when he was facing difficulties in the segmented part, he created a segment to *zoom in* on a difficult part. More than half of the participants (3/5) reported creating segments to focus on a problematic part.

Regarding TC's segmentation, we observed that it is far more elaborate than those of the dancers. TC created 25 segments for the first video and 19 segments for the second video and spent 2 hours per segmentation. TC's segmentation of the first video is shown in Fig. 5.6. She created four types of segments, with different foci and goals that are as follows:

- *Observational segments*: observe the dance phrase and dance along with the video. These segments are characterized by normal speed and one or two repetitions;
- *Technical segments*: specify technical information such as counting the steps or notify which leg starts;
- *Spatial segments*: cut the movement into space and orientation; and,
- *Detail segments*: detail specific difficult parts of the phrase. These segments are characterized by a short duration, a low speed, and a high number of repetitions.

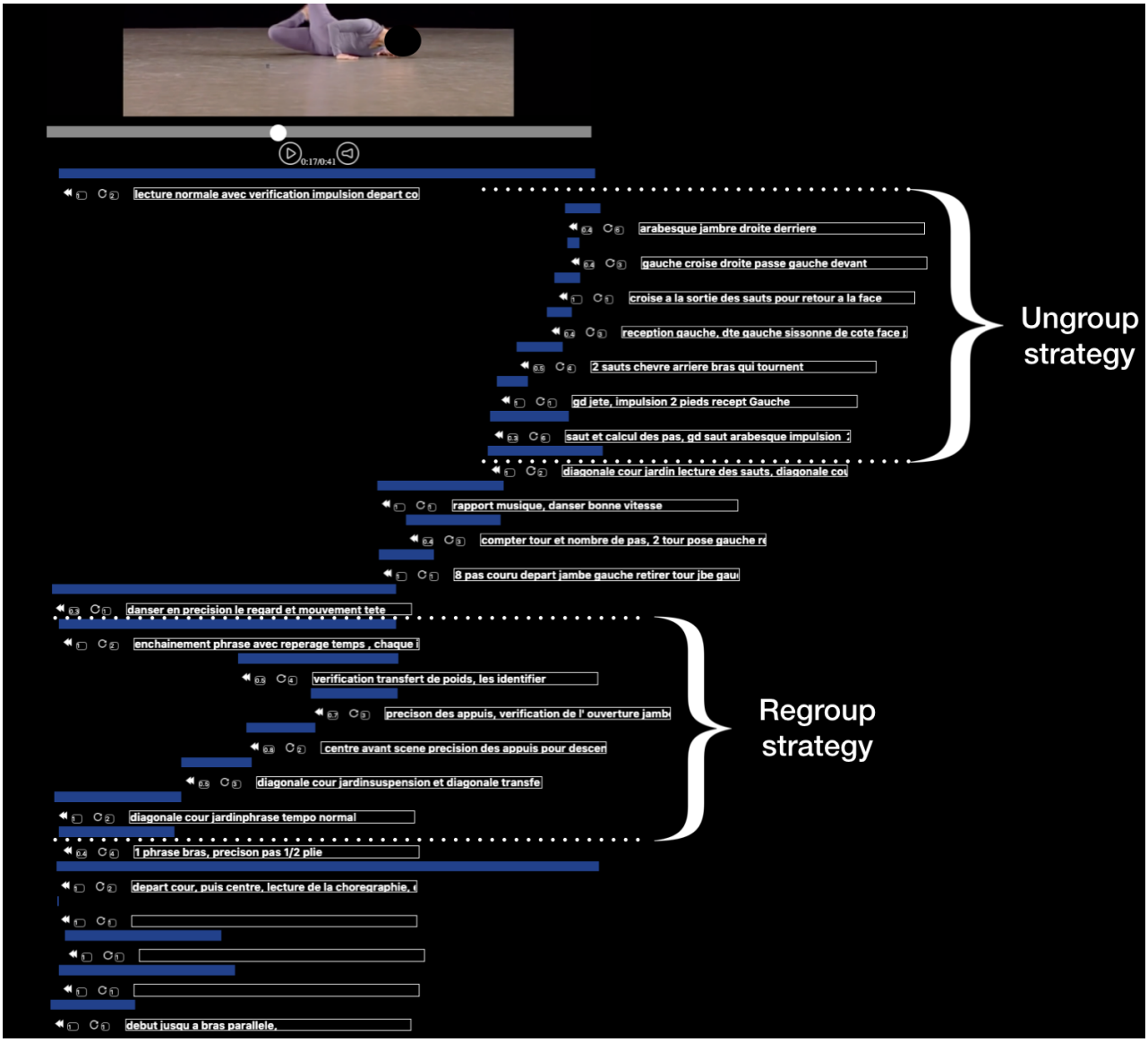


Figure 5.6. TC segmented the first video into 25 segments overlapping segments. We detected the same strategies of regrouping and ungrouping segments in her segmentation. (Old version of *MoveOn*)

5.1.6.3 Dance performance after personal and imposed segmentation

To compare the learning using TC's segmentation versus the dancer segmentation, we first report TC's scores (after the study) on dancers' expertise, which assesses each dancer's performance.

According to TC, P2 is the most expert dancer, while P3 is the least experienced dancer with no learning experience from a video. TC considers P1, P4, and P5 as intermediate dancers, even if P4 explained that she faces difficulties when learning from a video: *"For me, learning from a video is very complicated because the right and the left are reversed.*

Figure 5.7. The segmentation of P2, the most expert dancer of the session, contains 5 overlapping segments with a low speed rate (between x0.1 and x0.2). (Screenshot produced from an old version of *MoveOn*)

(P4)". Using TC's segmentation, the two least expert dancers managed to perform and improve their dance learning. TC stated that P4's performance was "*more precise*" and *cleaner* when she followed TC's segmentation. On the other hand, the most expert dancer (P2) performed the two dances flawlessly in both conditions. TC considered that P2 performed the best with P2's segmentation. For the two intermediate dancers (P1 and P5), TC evaluated their two performances at the same level (P1 presented a slightly lower performance with TC's segmentation while P5 a slightly better performance).

5.1.6.4 Dancers experience of personal and imposed segmentation

In terms of experience, the Likert scale analysis showed that all participants preferred their own segmentation compared to TC's segmentation. The dancers found that their segmentation helped them learn the dance phrase. When asked to rate the interface features with respect to the task, they stated that the lowering speed and repetition functions were useful for learning. Only P3, the most novice dancer, stated that TC's segmentation suited her because it was "*segmented with a lot of detail for the same sequence*" (P3). This is consistent with the fact that P3 performed better with TC's segmentation.

We identified two issues related to TC's segmentation that may impact the dancers' experience: the lack of control and confusion over the different segments. Most of the participants (4/5) expressed *frustration* when following TC's segmentation segment by segment. According to P2, that feeling was emphasized when starting the session in autonomy and then getting constrained in the second activity. This lack of

choice was particularly felt when the intention of dancers conflicted with that of TC. P2 argued that the *logic* of the segmentation was different. P5 and P1 stated that they got interrupted in their observation because the focus of TC was not the same than theirs: "*and it cuts me right in the middle of what I was looking*" (P5). Moreover, most of the participants (4/5) did not understand the intentions behind TC's segmentation. Although TC annotated all the segments, P1 argued that he did not understand *what he was supposed to look at*.

5.2 Discussion

In this study, we explored how students' practice schedule can be manipulated through segment history. We explored the difference between two typical pedagogical cases: self-scheduled learning by the dancer and learning from a teacher's schedule. Our results suggest that a segment history can be shared and used to fashion dance students' practice schedule. It appears that the teacher-created segmentation is more effective for introductory dance students, whereas personal segmentation is more suitable for expert dancers. Here, we discuss these findings and their implications for designing new technology that can support dance learning. Finally, we discuss the impact of the context as a social factor on the results.

5.2.1 MoveOn as a technology probe between movement learning and transmission

Using a segment history as a teaching tool was directly inspired by cognitive science literature. Instead of letting the students control their practice (self-control), we imposed a new practice schedule. Similar approaches were conducted during simple and complex skill learning tasks [Shea and Morgan, 1979, Carter and Grahn, 2016, Magill and Hall, 1990], imposing blocked, yoked, or random practice to students. The originality of this approach is to provide a schedule produced by an experienced dance teacher. We choose this approach due to the challenge of producing a practice schedule for dance.

Designing a learning schedule is a fundamental problem in pedagogy. *MoveOn* can serve as a medium between the teacher and dancers for instance, in distributed or remote learning. From the results, we suggest that while less experienced dancers performed better in the imposed decomposition, they still prefer learning with their decomposition. This result supports previous findings that learning practices

leading to better performance are not necessarily preferred by learners [Carter and Grahn, 2016, Kornell and Bjork, 2008]. Imposing a practice schedule also collide with the notion of deliberate practice [Ericsson, 2014], which can be detrimental to long-term acquisition.

Therefore, there seems to be a compromise to reach between the condition in which they perform best and the one they prefer. One approach could be the combination of both modes: a curated movement decomposition that learners can easily customize. We are currently not fully aware of all the phenomena that impact the felt experience and the level of success of a task [Bjork et al., 2013], but we highlighted significant starting points to explore this question. For intermediate or expert dancers, however, following the teacher decomposition seems ineffective. Our interpretation is that, through extensive practice, advanced dancers create functioning learning patterns that they can reuse across tasks [Ericsson et al., 1993]. However, their decomposition still helps them to visualize and reflect on their learning process.

This work opens new design opportunities and brings interesting questions for the design of interactive systems supporting physical practice in general. We believe that reusing and sharing segmentation patterns and practice schedule is a promising avenue for dance learning. More research is needed to better understand the trade-off between sharing practice schedules and supporting the idiosyncratic nature of motor skill learning.

5.2.2 The social nature of the dance studio

The dance studio is a complex social environment involving explicit and implicit interactions between dancers, dancer-teacher, and dancer-technology. This environment makes it hard to understand the impact of the group on the use of *MoveOn* and its impact on dancers' practice. Nonetheless, we observed social and collaborative learning aspects that contribute to HCI and Computer-Supported Cooperative Work (CSCW) in particular.

The last three chapters reported a series of studies that took place at different moments with different groups of dancers. An important contextual factor has been the difference between groups from different studies. In chapters 3 and 4, the participants were all intermediate or expert dancers with experience in learning dance choreography from video. They were recruited among our contacts and were highly motivated to participate in the study. The study presented in this chapter took place in a dance class, with heterogeneous expertise among

participants: two dancers were novices without prior experience learning from dance video, and one participant was a professional dancer with extensive experience of learning from video. During this structured observation, we observed unexpected reactions triggered by the task. Mainly, a dancer abandoned the study before the end of the task. This led us to question and challenge our methodological approach.

Our original approach in this work was to consider the first-person perspective as a tool to generate design ideas. This approach brought insightful knowledge on dancers' learning strategies and techniques during practice (as reported in the three studies). However, it also pushes dancers to learn the movements on their own, using a tactile device. Dancers in studies 1 and 2 were enthusiastic about the task, which we believe is due to their initial interest in being part of these experiments. However, the dancers in this study 3 were more resistant to the approach. For example, the dancer who could not finish the task further explained that the task reminded her of traumas encountered in childhood dance classes, where she had trouble learning dance phrases. This highlights a conflict between the embodied and social nature of learning (in a studio) and the isolated nature of the technology supporting learning. It is essential to consider group social dynamics, context, histories, and embodied practices that appear in the dance studio.

5.3 Chapter summary

We conducted a structured observation with six dancers and a dance teacher to compare learning from a self-created schedule with a teacher imposed practice schedule. We found that the teacher produced a detailed segmentation history for the dancers focusing on transition, observation, spatial and technical aspects, and details. The dancers were mostly producing segments when working on a specific aspect of the movements. They both used strategies of grouping and recomposing segments, working on movements transition.

We suggest that teacher-created segmentation is effective to teach introductory dance students, whereas personal segmentation is more suitable for expert dancers. Finally, we discuss the social and collaborative aspects of dance learning. Dance learning is not only learning individual steps. It is also a collaborative and social activity, and we are interested in understanding further the collaborative nature of dance learning. The following chapter describes a one-year longitu-

dinal study with a dance company re-staging a contemporary dance piece where we investigated collaborative dance aspects in detail.

5.3.1 Contributions

- Creation of two detailed segment histories by a dance teacher to teach dance video choreography.

- Identification of the teacher-created segmentation as an effective tool to schedule the learning of novice dance students.

- Identification of different types of segments created by the teacher: Observational segments, Technical segments, Spatial segments, and Detail segments.

- Identification of segmentation overlap. Expert dancers and the dance teacher overlap segments and manage transitions between each video part.

6

Exploring the Role of Artifacts in Collective Dance Re-staging

This chapter presents a 12-month longitudinal observational study with a dance company that re-staged a dance piece, taken from the contemporary repertoire and unknown to the dancers. I gathered the artifacts produced by the group and examined how they shape the group's learning process. I showed how dancers produced an ecology of artifacts with the aim of analyzing the choreographic ideas behind the dance and sharing it with other learners. I showed that sharing these artifacts was challenging because they are idiosyncratic and embody their creator's perspective and vocabulary. I then illustrated how dancers overcome this challenge by compiling artifacts and distributing the learning task among the group in order to create common knowledge of the piece, which improves the learning process.

This chapter includes written material from a paper submitted to the journal CSCW. The study was conducted by myself, the data analysis was conducted with Sarah Fdili Alaoui. This paper was a collaborative effort conducted with Sarah Fdili Alaoui, Baptiste Caramiaux, and Wendy Mackay.

I investigate the learning of dance phrases from video recordings in the previous chapter. Although the previous study was located in the dance studio and involved multiple dancers, dancers did not collaborate during learning. However, creating and learning a dance performance is highly collaborative, dancers must not only learn their own parts, but also learn how to interact dynamically with other dancers. Therefore, understanding the dance learning process requires a more

holistic approach, taking into account the situated nature of cognition, where human knowledge is grounded in its social, physical, and cultural context [Solomon, 2007]. In this chapter, I am especially interested in understanding how dancers work together to produce the final performance, with the longer-term goal of designing interactive tools that support dance learning's collaborative aspects.

Designing for collaborative dance learning requires an in-depth understanding of how dancers collaborate, and this can be completed by observing users *in the wild* [Rogers, 2011]. Within Computer-Supported Collaborative Learning (CSCL) and Work (CSCW) fields, there are a variety of methods to capture users' collaboration in the wild. A popular approach is to examine the artifacts produced by the group to understand the relationships between the different protagonists [Stahl, 2013]. Hsueh et al. [2019a] recently applied this method to creative practice. Digital and physical artifacts served to analyze creative collaborations between creators and performers in music and dance. I follow the same direction, using artifacts as a lens into the collaborative practices of learning dance and address the following research question: How do dancers learn a dance piece in a group? What are the different ways in which dancers interact with digital and physical artifacts in collaboration?

I collaborated with a dance company working on the re-staging of a professional dance piece from the contemporary dance repertoire. In this context, re-staging means that the company's dancers were required to learn and perform an existing dance piece unknown to them, as closely as possible to the choreographer's original idea. During this collaboration, I ran a longitudinal field study where I investigated how company's dancers interacted with digital and physical artifacts to learn and rehearse the dance piece collectively. I introduced the dancers to *MoveOn* and observed how it was used and integrated into their learning process alongside the other artifacts.

This chapter reports on a longitudinal observation study that I conducted with a dance company over one year. In this observational study, I examine the collaborative nature of dance, presenting the context, the dance company, and the dance piece. First, I introduce the context and methodology based on physical and digital artifacts. Then, I describe the results which contribute to a better understanding of how artifacts intervene in supporting the learning process and embodiment of dance movement. I show that participants create and appropriate an ensemble of heterogeneous complementary artifacts that help them to decompose and analyze the choreographic ideas under-

lying the dance. However, I show that sharing these artifacts is challenging because they embody their creator's idiosyncratic perspective and vocabulary. The results illustrate how participants overcome these challenges by building a common knowledge of these artifacts and distributing expertise among the group. I discuss the results in the light of the limitations of current approaches and provide guidelines for future technologies for supporting dance learning. I also emphasize the inherent complexity of collaborative dance learning.

6.1 Context

I am interested in how artifacts mediate the learning process of a group of dancers. I introduce different researches in CSCL and CSCW fields that investigate how artifacts mediate collaborative learning. I then review how physical and digital artifacts intervene in the specific context of dance learning and practice.

6.1.1 Artifacts in collaborative practices

The CSCL literature studies how computers mediate collaborative learning processes. As stated by Stahl [2013], knowledge building is mediated by the production of knowledge objects or learning artifacts. Learning artifacts are lasting, durable, and public objects created by the learner for a specific use [Sawyer, 2005]. They provide concrete evidence and a basis for evaluating knowledge building and interactions within a group [Stahl et al., 2014, Stahl, 2013]. Bødker and Klokmose [2012] showed that the relationship between artifacts evolves dynamically over time. They suggest the importance of considering artifacts' ecology over long periods through longitudinal studies.

While the CSCL and CSCW literature focuses mainly on cognitive learning tasks (for example, mathematical reasoning), there is much to be done in studying motor learning tasks and how artifacts intervene in this process. Such a gap in the literature is perhaps due to the assumption that practitioners might produce fewer artifacts when learning through the body. However, two recent studies [Hsueh et al., 2019a, Ciolfi Felice et al., 2016a] identified, in the specific case of dance, the various artifacts that dancers and choreographers create to document their practice.

6.1.1.1 *The role of physical artifacts in dance practice*

In the dance studio, practitioners produce physical artifacts such as notes, sketches, or notations of their dance ideas, performances, or choreographic structures [Stevens et al., 2005, Kleinman, 1975]. As depicted in [Kirsh et al., 2009], in a dance creation process, dancers and choreographers produce handwritten notes, which can, in turn, be exploited by researchers to get a better understanding of the dance-making process. In the same context, Ciolfi Felice [2018] showed that choreographers use drawings, text, diagrams, and videos primarily during the preparation of choreography, but rarely when reflecting upon the piece. She describes that both choreographers and dancers use artifacts to transmit choreographic ideas. However, these two studies do not investigate artifacts in the specific process of collaborative dance learning.

Both teachers and the learners produce physical artifacts in the dance studio. Artifacts act as objects that preserve a common memory across the group and can be studied to reveal a group's relationship. These artifacts are usually part of an ecology which refers to the idea that they are connected and influence each other [Jung et al., 2008], and should not be considered in isolation.

6.1.1.2 *The role of digital artifacts in dance practice*

Nielsen and Bødker [2004] show how digital artifacts are used in coordination with other physical artifacts such as paper notes or tools. In a dance setting, practitioners also produce digital artifacts to support dance transmission, production, annotation, and archival [Li, 2011]. Videos are among the most common type of digital artifacts used in dance studios. Today, dancers and choreographers video record their dance performances to share, transmit, or archive them. Of the modern and contemporary dance repertoire, video recordings act as a reference that allows dancers to learn repertoire pieces.

Recent studies in HCI investigated the combination of digital and physical artifacts to inform the design of interactive systems supporting choreographic writing [Ciolfi Felice et al., 2018] or enhance kinaesthetic creativity in dance improvisation [Hsueh et al., 2019b]. In a recent paper, Hsueh et al. [2019a] investigated how choreographers interact with the digital and physical artifacts that they create. They identified various approaches ranging from sculpting to layering to remixing these materials. The authors also identified the different roles that choreographers take to collaborate with dancers. They found that creators navigate the interactions with their artifacts and distribute the roles among collaborators fluidly. They argue that the fluidity and

"slippages" observed in real-world creativity opens creative possibilities and should be accounted for the design of systems supporting creativity. Similarly, the study of artifacts in collaborative dance learning contexts can shape our conception of tools supporting both the learners and the teachers.

6.1.2 Theories on embodied practices

Multiple theories provide insights for the design and study of digital artifacts that support embodied practices. These theories are essential for structuring the methodology and the understanding of artifacts created by the group.

6.1.2.1 Situated and embodied cognition

According to the theory of situated cognition presented by Solomon [2007], human knowledge is situated in a social, physical, and cultural context. Studying how human beings learn involves broadening the perspective on the context in which it occurs. Similarly, distributed cognition theory broadens the perspective on cognition to include interactions between people and with resources and materials in the environment [Hutchins, 1995, Salomon, 1997]. This theory highlights the environment as well as artifacts as an integral part of the cognitive process. Artifacts can convey, store, and distribute information among individuals and support practice and collaboration [Hollan et al., 2000].

According to Varela and colleagues [Varela et al., 2016] human cognition is embedded in a psychological and cultural context. Human knowledge is also situated in a social, physical, and cultural context [Solomon, 2007]. The distributed cognition theory broadens these visions by including interactions between people and resources and materials in the environment to human cognition [Hutchins, 1995, Salomon, 1997].

Thus, designing for dance learning involves a better understanding of the collaborative and distributed aspect of dance and the environment in which it occurs. Artifacts are a useful medium to study dancers' acquisition of knowledge and the collaboration between dancers and teachers in a real-life dance learning task.

6.2 The company and the dance piece

Collaborative dance learning is a complex process grounded in a social, physical, and cultural environment. Designing interactive systems for such context requires diving into the dance studio's reality. I had the opportunity to collaborate with a dance company called *De l'air dans l'art* (consisting of 12 dancers, a teacher and a company director), on the re-staging of *Frame(d)*. This piece is a fusion of two existing dance pieces (*Babel*[1] & *Myth*[2]) originally choreographed for the Eastman company[3]. *Frame(d)* requires a high level of skills and group coordination, which is acquired only through multiples rehearsal sessions.

[1] Babel: `http://www.east-man.be/en/14/20/` choreographed by Sidi Larbi Cherkaoui and Damien Jalet

[2] Myth: `http://www.east-man.be/en/14/31/` choreographed by Sidi Larbi Cherkaoui.

[3] `http://www.east-man.be/`

The re-staging of *Frame(d)* started in October 2018 with a five-day dance workshop and ended with the final performance in February 2020. Between October 2018 and February 2020, the rehearsal director led 27 sessions (111 hours), and the company director led eight sessions (32 hours), for a total of 35 rehearsal sessions (143 hours). Although not paid by the company, the 12 dancers were strongly engaged in the project and spent much of their free time rehearsing together. Fig.6.1 shows a timeline of the project. Each rectangle represents one or multiple rehearsal sessions, with the corresponding days and hours. Orange rectangles indicate the rehearsals the authors attended, and red dots indicate the performances.

6.2.1 Frame(d)

Frame(d) is a 20 minutes dance choreography for 12 dancers, composed of 9 parts. The dancers refer to them as: 1) *the line*, 2) *trios*, 3) *the bus*, 4) *the maze*, 5) *the leaves*, 6) *the technology*, 7) *the V*, 8) *the trio*, and 9) *the pyramid*. Each part of the piece presents particular characteristics that I describe below.

When the auditorium gets dark, the dancers enter the stage one after the other, line up, and sit on their knees facing the public, as shown in Fig.6.2. When the music starts, they collectively perform a fast sequence of movements, while moving forward and standing up. In the second part, dancers position themselves in trios on a diagonal and execute synchronized movements. In the third part, the group forms one trio, one quartet, and one quintet. Then they regroup in the middle of the scene and form a crowd, wherein a perpetual flow, they push each other to be in the foreground. This part is called *the maze* (Fig.6.3) because one after the other, they leave the crowd, following a squared path. Part 1 to part 4 is characterized by rapid and precise movements

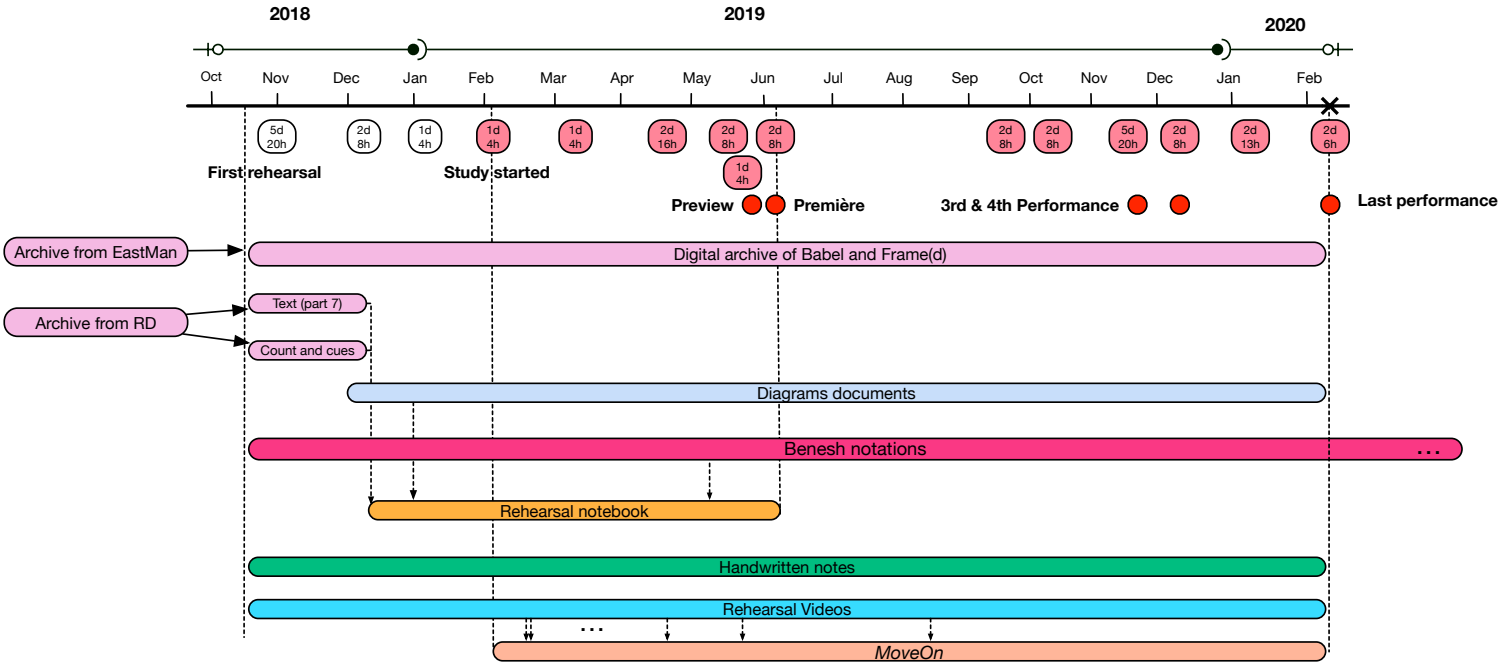


Figure 6.1. Project timeline. Between 2018 and 2020, the company held 35 rehearsal sessions for a total of 143 hours and performed 6 times (red dots). The company deployed and maintained different artifacts during the rehearsals.

Figure 6.2. The Line.

following the rhythm of percussive music, played with claves[4] and drums. At the end of part 4, the music stops and dancers fall on the ground.

Part 5 is a transition from a percussive to a calmer and more ambi-

[4] Percussion instrument

Figure 6.3. The maze

Figure 6.4. The leaves.

ent music. One of the dancers stands while the rest lie on the floor. The standing dancer wanders among *the leaves* (Fig.6.4) that gradually begin to move. In part 6, called *the technology*, a piece of electronic music gradually rises. The dancers perform robotic movements that are jerky and synchronized with the music. In part 7 , one dancer walks in the foreground to declaim a text (a transcript of a Ted talk given by the neuroscientist Vilayanur Ramachandran [5]). Gradually, the dancers take a V-shape (Fig.6.5) position where they all stand and perform the

[5] https://www.ted.com/talks/vilayanur_ramachandran_the_neurons_that_shaped_civilization

Figure 6.5. The V.

Figure 6.6. The trio.

same movements with their arms. After 2 minutes - halfway through the text - the speech is echoed by all the dancers. They declaim it all together while moving. Then start the second trio (Fig.6.6), and only three dancers stay on stage. Two of the dancers are on the floor and give their hand to a third dancer who stands (their hands will stay bound during the trio). Finally, in the last part, the rest of the dancers join the trio and form a pyramid of bodies. The soloist climbs this pyramid while trying to reach the sky (representing the Tower of Babel) (Fig.6.7).

6.2.2 Integration of a dance learning support system

In collaboration with the company director, I introduced *MoveOn* to the company.Because re-staging *Frame(d)* involves learning from several videos of dance, the company director saw this tool as an oppor-

Figure 6.7. The pyramid.

tunity to facilitate the dancers' interaction with the videos. Moreover, the dancers of the company were keen on exploring the use of new technologies in their learning process. At the beginning of the study, *MoveOn* was a technology probe, but with iteration with the company, it became a prototype and afterward a system that was used by the company. Initially, the goal was to study how dancers use *MoveOn* in a real context. However, I quickly realized that in real rehearsals dancers use an ensemble of tools that they compose together. Thenceforth, The study thus consisted in observing how *MoveOn* facilitates collaborative learning in interaction with a larger panel of tools and artifacts that dancers create and shared.

6.3 Methodology

In this study, I observed the dancers, the director of the company, as well as the rehearsal director in their real-life re-staging process. I gathered the physical and digital artifacts created by the company, and observed their use and evolution throughout the re-staging. These physical artifacts and technologies support the knowledge building

of the learners and provide us with a tangible trace of the learning process [Stahl, 2004]. I gathered and studied them in order to better understand the underlying mechanisms of collaborative learning of dance.

It is important to note that, prior to our collaboration, the dancers rehearsed with their teacher for 32 hours (in 2018). The four first parts of the piece were deeply analyzed by the dancers, and a primary version of the artifacts related to these parts were created. I intervened in the re-staging process after the creation of the artifacts. I witnessed most of the rehearsal process as I spent 111 hours with the dancers in the studio and were able to trace the lifespan of all the artifacts.

6.3.1 Participants

The 12 dancers (10 females, 2 males) were selected for *Frame(d)* by the company director for their dance qualities. They are experienced contemporary dancers with more than 10 years of practice. Seven of them are professional dancers and dance teachers (Dancer 2, 4, 8, 9, 10, 11 & 12). Of the 7 professional dancers, 2 of them (Dancer 4 & 12) are Benesh notators. Benesh notation is a codified way of "writing" dance scores for a given choreography. The five remaining dancers are not professional dancers but highly skilled practitioners.

The company director is a dance teacher with more than 40 years of experience in dance pedagogy. She is the backbone of the company and the driving force of the whole project. She is in charge of the administrative and financial support and coordination of rehearsals. Sarah Fdili Alaoui put me in contact with the company director for this project.

The Eastman company allowed the reproduction of *Frame(d)* only if the piece is reproduced identically. To fulfill this condition, the company recruited a rehearsal director. The rehearsal director is a professional dancer, from the Eastman's company, with 40 years of experience in dance. He already performed *Frame(d)* on stage, and his role was to transmit the choreography to the dancers and to direct the rehearsals. He directed half of the rehearsals in the presence of the company director. The other half was directed by the company director alone. In the following, I refer to the dancers as dancer 1 to 12, denoted by D1 – D12, to the rehearsal director as RD, and to the director of the company as CD.

6.3.2 Procedure

I conducted a longitudinal study with the dancers and the rehearsal director where I performed group discussions, interviews, and observations. During each rehearsal, I brought between three to six tablets and connected them to *MoveOn* through an internet browser. During the first rehearsal with the dancers, I presented the technology and its features (create a segment, navigate between videos, etc.). I invited the dancers and the rehearsal director to use *MoveOn* instead of their usual media player cautious not to impose the use of the technology. I observed how the dancers and the rehearsal director used digital and physical artifacts as well as *MoveOn* to support the transmission, learning, and rehearsal of the dance.

I conducted two group discussions with the dancers and the director of the company. I used a variation [Mackay, 2002] of the Flanagan's Critical Incident Technique for HCI. In the first group discussion (3 months after the beginning of the study), I asked the participants to explain their use of technology in dance studio, and how it shapes their learning. At the end of the study, I performed a second group discussion with the company. Step by step, I reviewed all the artifacts created and used by the company, to discover by whom, where, why, and when they were created, and how they were integrated into the learning process.

I performed an interview with the rehearsal director on the same topic. The interview lasted approximately 60 minutes and took place via Skype with the rehearsal director and in the dance studio with the dancers. Finally, I sent a form to each participant where I asked them to report on each artifact, if they used it, annotated it, shared it, when they used it, and if it was useful to them. During and after the study, the first author was in close contact with all the participants.

6.3.3 Data collection

Being in the field and attending the rehearsal allowed us to collect a copy of each artifact shared and maintained by the dancers. This includes dancers' handwritten notes, textual representation, sketches, musical scores, diagrams, Benesh notations, rehearsal videos, and tutorial videos. I present these artifacts in Table. 6.1, and for each one, I indicate who created it, the number of dancers who used and shared it. I kept a research notebook of my observations, where I documented the learning process with photos and notes. Additionally, I tracked the modifications that were made to *MoveOn* with *git*, a free and open-source Version Control System software. During all the interviews, I

recorded audio and video and took hand-written notes.

6.3.4 Data analysis

To analyze the group discussions and interviews, I first transcribed audio and video data and anonymized all interviews. I then performed a thematic analysis [Braun and Clarke, 2006] to extract themes related to the creation and use of the digital and physical artifacts. Two of the authors analyzed the data. Concepts were identified using open coding and then grouped into themes. We followed a bottom-up approach where we actively defined and named themes from participants' stories.

6.4 Results

In this study, we observed that learning dance relies not only on one tool but on an ensemble of heterogeneous and complementary artifacts that the dancers create, appropriate, and share (see Table 6.1). We describe hereafter the purpose of the artifacts created which is to help decompose movement and focus on specific aspects of the choreography (the rhythm, position in space, etc.). However, we illustrate the challenges around the readability and accessibility of these artifacts that is due to the fact that they highly embody their creators' perspective, expertise, and personal vocabularies. Finally, we show how the participants overcome these challenges by compiling and appropriating the artifacts and by distributing the knowledge among each other.

Artifacts	**Created by**	**Used**	**Shared**
Tutorial videos	RD, D2, D4, D5, D9, D10	9	5
Rehearsal videos	RD, CD	12	0
Video of *Frame(d)*	Eastman (dance company)	12	-
Benesh notation	D4, D12	2	2
Rehearsal notebook	CD, D3	10	0
Textual representation of *Technology*	RD	8	1
Accentuation of Babel music	RD	10	1
Rhythmic score	D4	8	1
Diagrams of spatial position	D5	7	2
Text to memorize (part 6)	Eastman (dance company)	8	3

Table 6.1. The list of artifacts created, used and shared by the dancers, the rehearsal director, and the company director.

6.4.1 Artifacts are used to decompose or simplify the choreography

The dancers and RD created several physical and digital artifacts related to different parts of the piece. Each artifact takes a different form, such as videos, texts, diagrams, scores, or notations, among others. We found that artifacts help decompose movement and focus on specific aspects of the choreography (the rhythm, position in space, etc.). Moreover, we found that the information represented in the artifacts used is complementary.

6.4.1.1 Digital artifacts help decompose movements

RD explained that videos are convenient to represent the "*movement of the body itself*". They are the primary type of (digital) artifact that the dancers use in the studio during the learning process for various purposes:

> *I used them [the videos] at the beginning to specify the movements and the counts (with slowed down music). In the middle, before rehearsals to refresh my memory. But not at the end, because I already embodied the rhythm and these videos made me doubt.* (D2)

Besides the video of *Frame(d)*, the dancers and the rehearsal director also filmed and shared numerous other videos. RD produced and shared video tutorials where he *marked* the movement (i.e. performs it in less than a complete manner). Marking movement is a technique that allows the dancers to simplify the choreography by isolating elements of it, such as upper body movements, rhythm, or accentuation [Kirsh et al., 2009]. Most of the dancers (10/11) found these video tutorials useful to understand the difficult parts of the dance.

6.4.1.2 MoveOn help decompose movement

MoveOn was used to decompose videos and to focus on its parts. Throughout the months during which the dancers used it, they have acquired a large expertise in editing their videos with it. For example, D6, D3, and D2 relied highly on *MoveOn* to learn their trios (part 2). Indeed, D6, D3, and D2 expressed that the tool was useful for these specific trios where the rehearsal director's knowledge was lacking.

> *It [MoveOn] was very useful for parts that RD did not teach to us. The options of slowing down and selecting a very short extract, really helped me to break down the steps and to unravel the trio with D6 and D3. It is a task that usually requires a lot of time and effort and* MoveOn *simplified it.* (D2)

MoveOn has also been appropriated by RD to decompose the music.

RD created segments according to the music rather than the video. He tweaked the speed of the music to slow down the dance. He reports that:

> *I use it more like a musical software. I know the choreography, and now, I prefer to rely on the music and not on the video. What I need is to start at a precise point in the video where the music begins. It is much more precise than my other tools actually.* (RD)

While most dancers found *MoveOn* useful, they deplored that it was not present at the beginning. As explained by D6, "*It would have been perfect to have the tool at the beginning of the learning, it came a little late*" (D6). Indeed, *MoveOn* allows decomposing movements into chunks, which can be useful in the early phase of analyzing the dance. When we introduced *MoveOn*, parts of the choreography were already analyzed. This led dancers use it to analyze mostly the parts of the dance that were not yet known to them. This is illustrated in Fig.6.8 where three dancers use *MoveOn* to decode their trio.

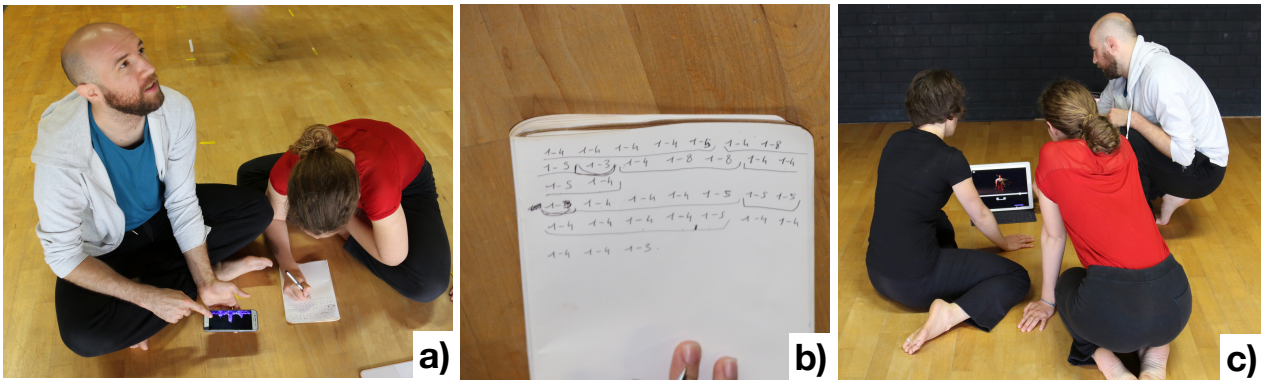


Figure 6.8. Pictures of D4, D10, and D12 working on their trios. The picture a) represents D5 and D10 counting the steps from videos and annotating it in their notebook (b). In the picture c), the three dancers watch their part with *MoveOn*.

6.4.1.3 Physical artifacts help focus on specific aspects of the choreography
In addition to digital artifacts, the participants produced four physical artifacts that helped them focus on specific elements of the piece such as the rhythm, the choreographic cues, or the position in space.

At the beginning of the re-staging, RD shared with the group two documents that he created when he was learning *Frame(d)*, eight years before. The first document is a text representation of part 6 of the choreography (Fig.6.11a). RD shared this document to help the dancers better understand what he calls the *choreographic cues*:

> *There is a lot of cues, inside each scene. Cues are reference points that indicate when to begin or end a movement. It's usually musical or visual, either you listen to the music or you see a landmark. These are indications of when you*

should start or stop your movements. (RD)

Complementing RD's document, D5 created seven diagrams that represent each part of the piece (Fig.6.9 and Fig.6.10). In these diagrams, he depicted the position of each dancer in space in order to "*structure the dance phrases as a whole*" (D5), and to see where "*interactions are located*" (D5).

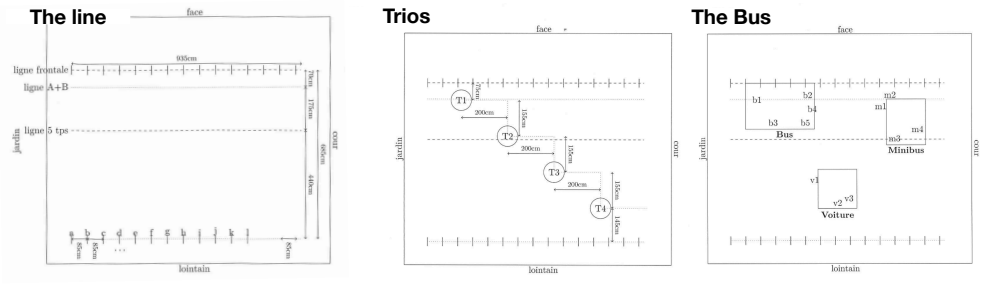


Figure 6.9. D5's schema of the *line*, *trios*, and *bus*.

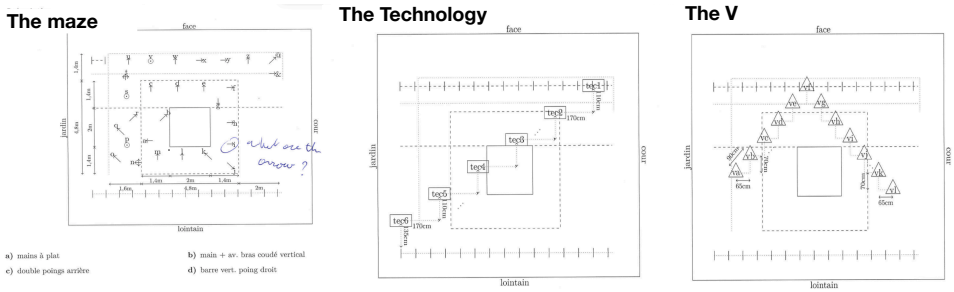


Figure 6.10. D5's schema of the *maze*, *technology*, and *V*.

RD provided a second document from his archives that represents the accentuation of the music of part 1 (shown in Fig.6.12a). In this document, the red numbers highlight the rhythm and the accent of the music, where movements must be *percussive*. RD reported that this document resulted from a problem he encountered to embody the rhythm. His strategy was to write down the accents of the music on paper and to memorize it:

> *Several kinds of learning exist, either you can memorize it musically or you can visualize it. This document was handy for that. Here, I just isolated the musical side in terms of pause and movement, with colors and punctuation.* (RD)

D4 (the Benesh notator) revisited this document and represented the same information through a formal musical score (Fig.6.12b). D4 chooses this representation for its unambiguously codified structure.

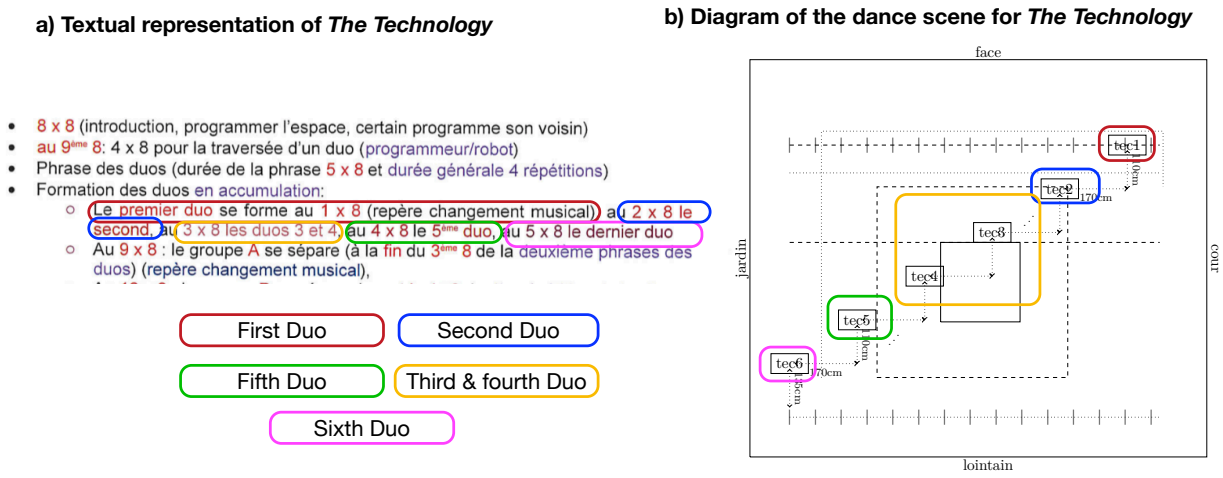


Figure 6.11. Two diagrams present two different ways of portraying the rhythm and accentuation of the music in *The Technology* part). On the left, RD presents a numerical representation of the music with the accentuation in red. On the right, D4 represents the rhythm in the form of a musical score. Accentuations are represented with large numbers.

6.4.1.4 *Complementarity of artifacts*

In Fig.6.11a) and Fig.6.11b), we used colored rectangles to highlight how both documents created by RD and D5 refer to the same part, but represent different, yet complementary information. On the left, RD used a text to explain dancers' position, while on the right D5 proposed a visual representation in the form of a diagram.

While the form and language used to represent information varied from an artifact to another, the group considered them equally important to focus on specific aspects of the piece with complementary views. Half of the dancers (6/11) found RD's text representation useful to understand choreographic cues, more than half of the dancers (8/11) found D5's diagrams useful for clarifying the space, (8/11) and (9/10) dancers found D4's musical score and RD's representation of the accentuation useful for memorizing the rhythm.

RD argues that these diverse representations of the same information were important to create a complementary view of the dance:

> *I have the feeling that we all sharpened one thing, and all learning angles are complementary at different levels, we have different learning strategies.* (RD)

6.4.2 Artifacts' idiosyncrasy limit their sharing

We observed many challenges to the use of the artifacts by participants other than their creators. Firstly, each artifact represents the piece with their creator's own perspective and vocabulary. These personal approaches used to represent the information sometimes collided with

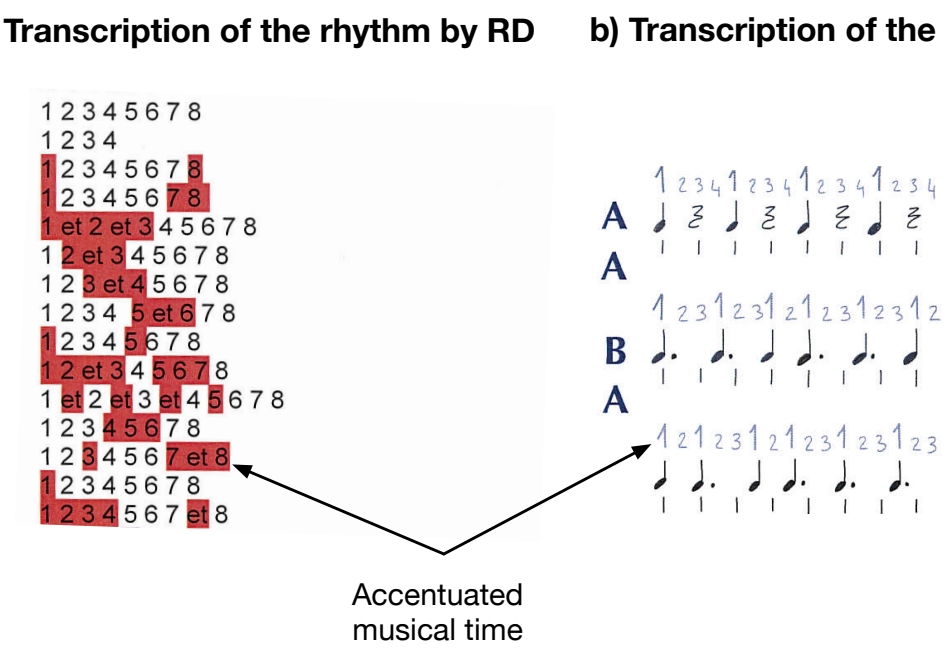


Figure 6.12. Two diagrams present two different ways of portraying the rhythm and accentuation of the music in the sixth part of the piece. On the left, RD presents a numerical representation of the music with the accentuation in red. On the right, D4 represents the rhythm in the form of a musical score.

other learners' ideas of the choreography. For example, D11 stated that she would have described differently the diagrams produced by D5:

> *I did not used D5's document [diagrams] because he oriented it in one way, and I would have oriented it in the opposite way. Because we think and work differently.* (D11)

D11 did not want to use D5's diagrams because there was a gap between how D5 represented the diagram and how she would have done it. The direction of the scene was "*awkward*" to her and did not conform to her mental model of the scene.

Secondly, the lack of a common vocabulary also limited the access to the artifacts. D2 reflected on how such issues arose in the rehearsal notebook.

> *If we make a common document, how can we express it so that it speaks to every dancer, but at the same time we need this common document because sometimes we forget these corrections which are useful to all of us.* (D2)

Although sharing artifacts was considered valuable in order to build the group's common understanding of the piece, such collective ac-

tion required communication and "*agreement upon the vocabulary used*" among participants (D11). D11 argues that creating a common tool requires. Compiling all the artifacts is a way to offer multiple representations, but it doesn't solve this issue. RD argued that producing videos was a way to overcome the limitations due to personal vocabularies, because the body is "*the common language for dancers*" (RD), and videos are the most "*readable*" artifacts for dancers.

Finally, we observed that expertise limited access to artifacts. Some artifacts followed precise rules of composition and required a certain expertise, which can elude some learners. For example, D4 created a musical score (Fig.6.12b), which requires a musical theory training to read it. Three dancers reported that they could not use it. Another example is Benesh notations, a highly structured form of dance notation that requires extensive training to read or write it. D4 and D12 are two Benesh notators. They notated the whole piece to create a sustainable archive of it (an example of the Benesh notation of part four, can be seen in Fig.6.13). Their notations were considered valuable but not accessible to other dancers. D1 stated: "*You have to be a notator to read Benesh notation, and you cannot access it otherwise.*"

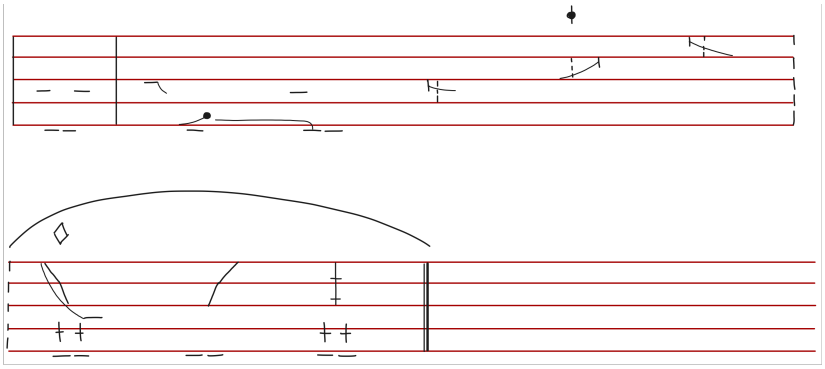


Figure 6.13. An example of a Benesh score from part 4, created jointly by D4 and D12.

6.4.3 Overcoming challenges of sharing artifacts through compilations

We observed that compiling documents and videos allowed participants to overcome the challenges around the artifacts' accessibility.

6.4.3.1 Compilations to create an ecology of artifacts

Throughout the whole learning process, participants compiled the artifacts that they consider useful to the group. We illustrate the ensemble of artifacts around *Frame(d)* in Fig. 6.15. This figure shows that the participants (depicted as circles) created a system where heterogeneous digital and physical artifacts (blue rectangles) co-exist. Artifacts

are grouped through compilation platforms (red rectangles), which provide the same information to all the participants. Through these platforms, the participants have access to the artifacts produced by other participants and are free to use the artifacts they want or need. They pick among all the artifacts created by the group to appropriate, adjust, or tweak them to accommodate their personal learning practice. Thus, the dancers create their own network of artifacts, which is considered as an ecology of artifacts, following Vyas and Dix 's definition [Vyas and Dix, 2007].

6.4.3.2 Compilations to facilitate dancers' access to dance knowledge

In the early stage of the re-staging, the participants mainly used emails to share their documents and videos. However, limitations rapidly arise: internet access is usually limited in dance studios and dancers do not necessarily bring their laptop to the rehearsals. Under the impulse of CD, D3 created the *Rehearsal Notebook*, a document that compiles all documents created among the group. CD printed twelve versions of this rehearsal notebook and distributed it to all dancers. The first version of this document regrouped:

- the text learned in the part 7,
- the musical score wrote by RD and D4 (Fig.6.12a, 6.12b),
- a diagram of part 6 (Fig.6.11b),
- a textual representation of part 6 (Fig.6.11a); and
- the schedule of all future rehearsals planned by CD.

This rehearsal notebook provided a unique source of information to everyone, as D3 explains:

> *Each time we had many comments and many things to say, a lot of things to add. We needed to condense all of this in a handy document.* (D3)

The dancers appropriated this document for their personal use, as explained by D2: *"At first, everyone has the same notebook, and then everyone built on it."*. For example, D12 cut out and integrated part of the rehearsal notebook into her own dance diary (depicted in Fig.6.14). We observed that five dancers annotated their version of the rehearsal notebook, taking personal notes on the different sections.

RD described that the goal of using compiling platforms is to disseminate the same information among all individuals. Although the learning artifacts were personal and thus sometimes difficult to access by others, compiling them served to establish a common memory and

structure the piece for the group.

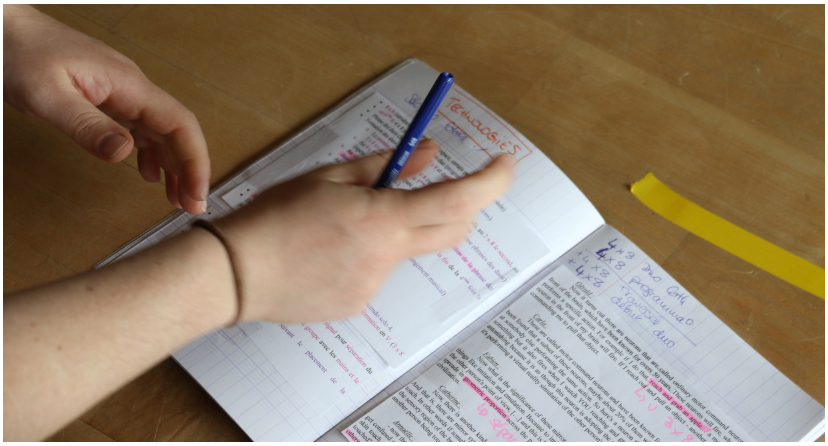


Figure 6.14. D12 annotated and integrated part of the rehearsal notebook in her personal notebook.

6.4.3.3 *MoveOn to facilitate dancers' access to videos*

Similarly, the participants used digital platforms to regroup and share dance videos. While outside the dance studio, CD shared most of the videos with an online video platform (Vimeo), inside the dance studio, the participants used *MoveOn* to upload and gather their videos. Both Vimeo and *MoveOn* served to compile all videos in one place. Additionally, *MoveOn* stored a trace of the dancers' learning pathways: how they segmented the videos, how many repetitions they needed for each segment, the speed in which they displayed it, and their personal annotations of it. Therefore, through the tool, dancers could come back to their rehearsal strategy simply by playing their segments one after the other. Thus, *MoveOn* served to compile, store, and share rehearsals' videos and augment them by saving a trace of each dancer's learning schedules. According to RD, these compilation platforms unified the learning tools used by the group:

> *It unifies people. It's individual needs, but the more you share them, the more you allow people to be in unison.* (RD)

6.4.3.4 *Compilations to create an ecology of artifacts*

Throughout the re-staging process, I observed that the roles taken by the dancers shift from the role of learners of the piece to the role of referent dancer for the other dancers. Similarly, the artifacts evolve with time and deviate from their initial purpose, moving from archival tool, to learning tools, or performance support tools.

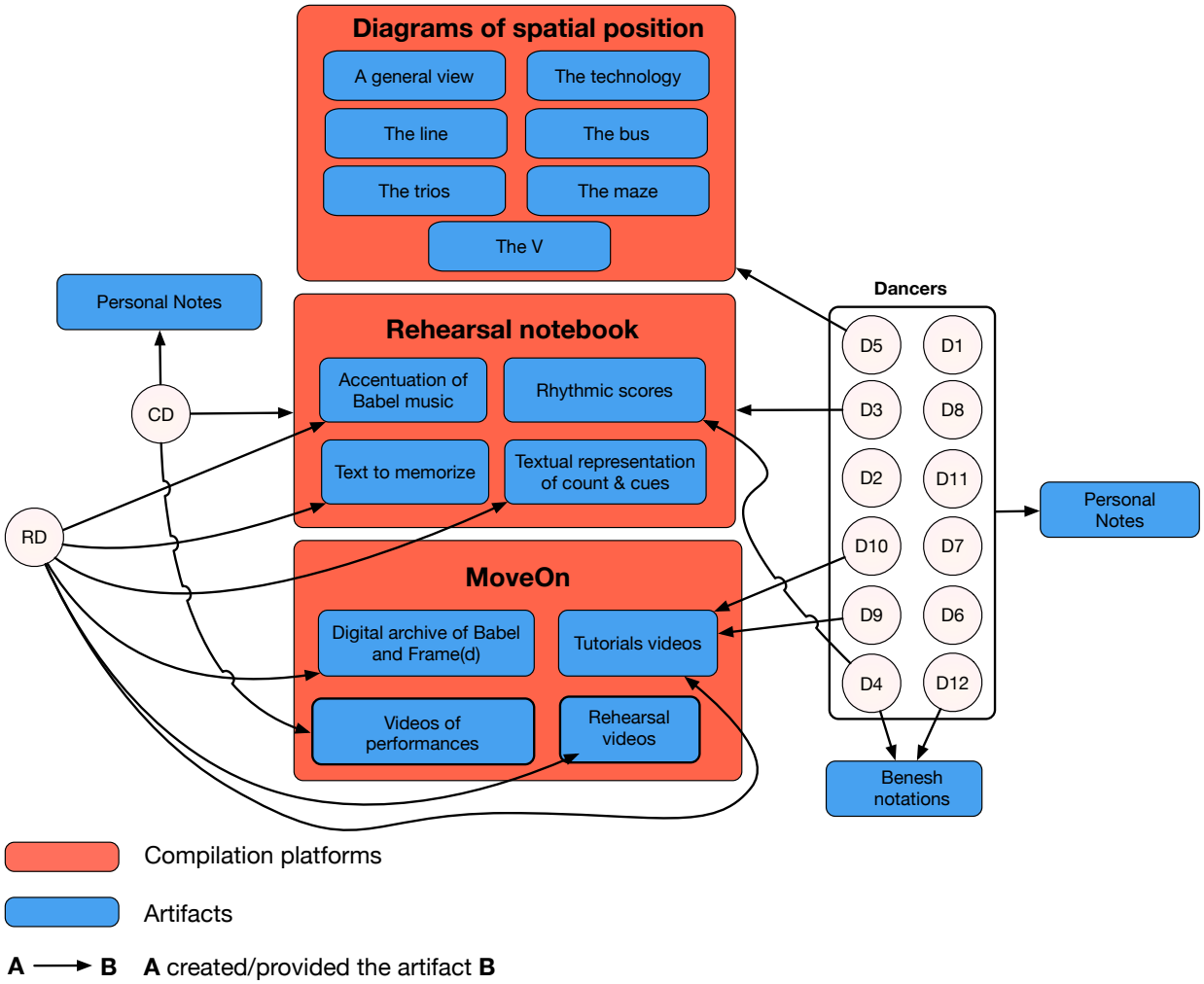


Figure 6.15. This schema depicts the different links between the participants (circles) and the artifacts they shared with the group (blue rectangles). The compilation platforms (red rectangles) group the artifacts in one place and play a central role in knowledge sharing.

6.4.4 Overcoming challenges of sharing artifacts through appropriation and distribution of expertise

Dancers appropriated the artifacts In order to overcome the challenges related to their access. Moreover, the group distributed the tasks according to new expertise that emerged among the group.

6.4.4.1 Dancers' appropriation of artifacts over time

We observed how dancers appropriated the artifacts available throughout the process. This is the case of the initial video of *Frame(d)* provided by the Eastman company to the dancers. This video was originally made for the promotion of the piece, but the dancers used it as a reference point to learn *Frame(d)*, while RD relied on it to clarify movements. Another example is the videos of the public performances of

the piece shot by CD. According to CD, these videos initially helped to archive *Frame(d)*, promote the piece, and run fundraising campaigns for future projects. However, the dancers re-purposed them to improve, reflect, and criticize their performance.

Other physical artifacts also shifted from their initial purposes. For example, D5's diagrams became useful before each public performance to place colored tape that represents landmarks on the stage.

Benesh notation is another example of how physical artifacts shifted function. For a notator, Benesh notation is a tool to analyze and take note of the movements (D4 takes most of his notes in Benesh writing). Initially, Benesh notation was made to safeguard the piece. However, the Benesh notators used these scores to clarify aspects of the piece to the rest of the group and give them feedback on their performance:

> ***D11**: There is a moment when having a notator in a group brought something into the discussions. For example, when RD was teaching something, there were times when D4 said it differently, counted it differently, specified it differently, or said it in another way that was sometimes easier to understand. The fact that a notator has this ability to analyze the movement helps a lot.*

6.4.4.2 Distribution of roles according to dancers' expertise

According to CD, the dancers progressively mastered different aspects of the dance that are *complementary*. For example, D5 mastered the space and the representation of the scene, D11 and D9 embodied the rhythm precisely, and D4 and D12 had facilities to analyze and explain movements. Due to their expertise, the group considered them as *referents*. Therefore, they acted as teachers that corrected other dancers and provided precision on the aspects of the dance that they mastered. D2 explained that "*In the end, we know there is one dancer who truly knows one part of the piece. The text for you, the rhythm for D9. We shot a film of you, and we used you as the basis for any questions we might have—almost a referent on each part...*" (D2).

We observed that such direct communication replaced the use of the rehearsal notebook at a later stage of the rehearsals: "*I haven't used my notebook since... I know where it is, in a little closet, but I prefer to rely on other dancers*" (D11). According to D1, referent dancers held a "*collective kinesthetic memory*" that is key in the group's learning, and that is "*not visible in any document*" (D1).

We also observed that dancers relied on referent dancers at a later stage of rehearsals instead of RD to learn the dance. RD's role then

shifted to that of the choreographer, giving instructions on how to perform the piece (intensity, quality of movement) rather than teaching the movement itself.

In addition to looking at referent dancers (D5, D2, D4, D9, D10), the group asked them to generate video tutorials zooming into the specific aspects of the choreography that they mastered. For example, RD filmed D4 performing part 4 of the piece, in close-up, counting the counts. Similarly, RD filmed R10 performing the third part of the piece. These videos allowed the group to "*rely on a good dancer to learn the difficult dance phrases*" (D5).

6.5 Discussion

Our findings emphasize how heterogeneous and complementary artifacts that the dancers create, appropriate and share, are key for the collective task of learning dance.

6.5.1 Providing analytical tools for dancers

We found that, in a re-staging task, the participants produced an ensemble of artifacts that serve to analyze the dance by decomposing, simplifying and isolating movement, and focusing on different aspects of the choreography. Similarly, *MoveOn* was exclusively used to segment and thus simplify the dances where knowledge was lacking. Our results show that the artifacts that served to analyze in-depth elements of the choreography became external representations that build "*scaffolding for thought*", as Kirsh termed [Kirsh, 2010]. This appeared to be a fundamental part of the learning process. This emphasizes that learning dance is not only driven by physical training but also by the ability to analyze the underlying choreographic ideas (space, the position of the dancers, rhythm, etc.).

We found that most of the participants' physical artifacts were used to extract, visualize, and focus on these choreographic elements. For example, D4 produced a musical score (Fig. 6.12.a) to study and memorize the rhythm independently from the rest of the choreography. Thanks to such an external representation of the rhythm, the choreographic structure become clearer and more visible to the learners [Kirsh, 2010].

The use of artifacts to visualize choreographic structures has been ob-

served by Ciolfi and colleagues [Ciolfi Felice et al., 2016a] in their study of choreographic writing. The authors observed that choreographers generate what they call "*choreographic objects*" that embody their choreographic ideas. These objects are heterogeneous and can be represented by drawings, texts, diagrams, or videos [Delahunta et al., 2004]. These representations structure the piece and allow to transmit it to the dancers. This echoes our findings where the artifacts created served to make "choreographic objects" visible, for example the position and relationships between the dancers, the timing, or the rhythm.

- **Implication 1**: Designing interactive systems for dance learning should encourage dancers in analyzing movements as a complement to physical practice (which is mostly considered in existing systems).

6.5.2 Accounting for the diversity of learning methods

The results showed that artifacts embody the perspective, expertise, and personal vocabularies of their creator. This is the main challenge around the readability and accessibility of artifacts. The participants overcame this challenge by compiling and sharing them to build a common understanding of the dance.

Our results illustrated how the same choreographic ideas were represented with different artifacts and expressed with different forms and languages depending on the perspectives and expertise of their creators. While some participants preferred videos, others memorized better with text or diagrams. We showed the different ways dancers described the dance in text, annotated it with diagrams and annotation languages, or using *MoveOn*. Such diversity in the learning tools can be related to the learning style model of Felder et al. [Felder et al., 1988]. According to this model, there are multiple types of learners, in particular visual and verbal learners. Visual learners tend to remember best when they look at something while verbal learners are more comfortable with written and spoken explanations. Therefore, presenting the same information through different forms, tools, and languages is a way to embed all the participants' learning preferences. We showed that such diversity, while preserving personal styles, limits how information is accessible to others that do not share the same learning style, expertise, or language.

Designing technology to support learning should provide flexibility in representing the information to include the diversity of learning styles. We suggest that reification can be an appropriate principle to support

this. Reification is a design principle within the instrumental interaction model proposed by Beaudouin-Lafon [Beaudouin-Lafon, 2000], which consists on making an element of the choreography visible and persistent, by *reifying* it into an interactive object. By reifying different choreographic ideas into a multiplicity of tools, a designer can allow the users to navigate between different forms and representations of the same information. *MoveOn* reifies dancers' personal way of segmenting and labeling movement. By doing so, the tool accounts for the different foci and languages that dancers use to characterize movement while offering them a versatile interactive tool that facilitates segmentation and annotation tasks in learning.

- **Implication 2**: Designing interactive systems for dance learning should ensure the diversity of the learning methods, and this could be facilitated by the principle of reification in user-centered design.

6.5.3 Celebrating shifts in roles and artifacts

We found that in the process of learning *Frame(d)*, some dancers shifted roles and became referent for the group. We also found that artifacts shifted purposes and were re-appropriated by the participants. Therefore, dancers' roles and artifacts' functions are not static and evolve over time. This echoes the findings of Hsueh et al. [Hsueh et al., 2019a] in their study of the creative process in dance. They showed that the roles of the performers and creators alternate between author, curator, planner and interpreter, creator and improviser. They also showed that the interactions with artifacts during the creative process shifted fluidly from sculpting, layering, and remixing. They call these shifts "slippages" and argue that taking them into account in designing creativity support tools drive creativity forward by *opening up pathways into the future*. Our results illustrate the importance of these "slippages" of roles and interactions in the context of dance learning. We showed how dancers re-appropriated various documents and artifacts and integrated them into an ecology of tools that support their own personal learning journey. We also showed that the roles are always re-defined throughout the process, resulting in a highly collaborative and constantly renewed learning process.

- **Implication 3**: Designing interactive systems supporting dance learning should be assessed over time and ensure to support the diversity of dancers' roles among learner, referent, or choreographer.

6.5.4 Supporting a distributed expertise among the group

The phenomenon of a dancer becoming a teacher has already been reported by contemporary dancers to be a factor that positively impacts long-term memory [Stevens et al., 2019]. This phenomenon requires the dancer to acquire a level of expertise before being able to teach the piece. Brown et al. [Brown et al., 1993] explain that because expertise is distributed among a group of learners, each student specializes in one aspect. Our study of the group's learning process of *Frame(d)*, illustrated how some dancers built expertise in the rhythm, while others preferred spatial positioning. The group then took advantage of such diversity in expertise that altogether became complementary to teach all aspects of the dance. Our results also suggest that the artifacts served to build their creator's expertise. For example, D5 mastered the spatial aspect of *Frame(d)* by creating his spatial diagrams.

- **Implication 4**: Technology supporting dance learning should foster distributed knowledge and transmission of expertise among the group, enabling role shifting between members of the group.

6.6 Chapter summary

In this chapter, I ran a longitudinal study over the course of one year, where I investigate the use of digital and physical artifacts in the restaging of a dance choreography. It involves twelve dancers, a rehearsal director, and a company director in a collaborative process fragmented over time.

I used artifacts as a lens into the collaborative practice of dance restaging, to understand how dancers collaborate and how artifacts mediate this collaboration. The participants produced and shared several heterogeneous artifacts, and I showed how artifacts are used to analyze, decompose, simplify, isolate, and focus on different aspects of the choreography. While videos were a common and accepted tool for dancers to focus on movement and music, the rehearsal director and the dancers also produced a rich network of physical artifacts. Paper artifacts represented knowledge in different forms such as textual or graphical, depending on the expertise, the vocabulary, and the viewpoint of their creator. Such a plurality of forms made it possible to encompass the learning preferences of all dancers but also posed challenges in terms of accessibility. I showed how artifacts were made accessible among the group thanks to physical and digital compiling platforms, which allowed spreading the same information to all the

participants.

To conclude, artifacts played an important role in the re-staging of *Frame(d)* and this study contributes to a better understanding of the complex artifact ecology involved in the re-staging of a contemporary dance piece. The results suggest that dance learning combines movement learning with a rich cognitive enterprise which requires the analysis of choreography. Future work should explore avenues for designing tools that support dance learning by making choreographic elements and structure interactive, visual, and tangible. In this direction, this work provides insight into the possibilities that artifacts offer for the creation of tools supporting dance learning.

6.6.1 Contributions

- Description of the artifact ecology created by the company when re-staging *Frame(d)*.

- Identification of artifacts as tools for decomposing, simplifying, isolating, and focusing on different choreography aspects. Dancers use digital artifacts to analyze and share dance movements, while physical artifacts focus on choreography elements, such as rhythm, space, etc.

- Description of the impact of dancers' expertise, vocabulary, and viewpoint on the artifact they produce. The group represented the same information through different artifacts with different forms. This plurality of forms allows dancers to choose among a variety of tools to understand the same information. However, this poses challenges in terms of accessibility.

- Identification of compilation platforms that regroup multiple artifacts at a single place. Compilation platforms are both physical and digital, and enable distributing the same information within the group, which allows for shared memory to emerge.

- Description of dancers and teachers' role shifting during the learning process. Dancers develop expertise on specific parts of the choreography and become referent dancers to the group. Memory is distributed not only in artifacts but also in dancers' bodies.

7

Discussion and limitations

This chapter explores the insights, challenges, and limitation of designing interactive tools to support contemporary dancers in both individual and collaborative dance learning processes. I first discuss the methodological approaches that I followed to study dance learning. Then, I discuss how artifacts can support the dance learning process. Finally, I reflect on the challenge of capturing traces of the learning process with technology and using reification principles.

This thesis focuses on designing interactive tools to understand and support dance learning from videos in individual and collective contexts. Chapters 3, 4, and 5 investigated the process of segmenting dance video in individual settings where I focused on saving a trace of the learning process. Chapter 6 implies a much more complex landscape involving multiple dancers learning in collaboration. I will refer to the studies conducted in the order in which they appear in the thesis, as follows:

- Study 1: Interviews with the dancers
- Study 2: Workshop with documentation materials
- Study 3: Workshop with *MoveOn*
- Study 4: Structured observation with the teacher and dancers using *MoveOn*
- Study 5: Longitudinal study with digital and physical artifacts (including *MoveOn*)

7.1 Conducting various methods to understand embodied knowledge

Before designing *MoveOn*, the challenge was to identify implicit embodied knowledge. I started my design process by conducting interviews with expert contemporary dancers. I found a set of seven learning techniques employed by dancers during their learning. This suggests that dancers use a rich repertoire of techniques. The learning techniques can be seen as a set of "tools" that dancers use to rehearse specific dance skills. Kirsh [2013] showed that marking is a more effective technique to rehearse memory or timing than full-out practice. This study shows that learning to dance is not just repeating a perfect movement but also picking the right techniques to rehearse the right skill. I shed light on a broader set of techniques that Kirsh tested in his experience. In future work, I see an interest in investigating how learning techniques can be useful to build which skills. For example, we showed that dancers apply movement variations during learning to explore and adapt movements. Herzfeld and Shadmehr [2014] argue that, in the early stages of learning, applying movement variations can be seen as an exploration of the motor controls space, which showed to be beneficial for learning. Future studies should explore how dancers apply variations to explore and and learn dance movements.

During the following workshops, I observed that dancers used other techniques than the ones I identified. I showed in study 2 that one of the participants drew on paper to visualize the choreography trajectory. This suggests that I did not identify all the learning techniques during the interviews with the dancers. I see two reasons for this: First, I interviewed dancers coming from contemporary dance, which certainly influenced the set of techniques reported. As explained by Enghauser [2003], dance learning relies on a practice that can be heavily influenced by traditions carried by dance educators and the type of dance [Karin, 2016]. Secondly, I asked dancers to focus on and explain very specific episodes. Later on, during workshops three and four, I was engaged in studying learning in a real-world context and extracted more techniques. Therefore, future studies should look for alternative learning techniques with dancers from various backgrounds and in real dance learning contexts. I believe that our methodology can be extended to other contexts, such as other types of dance, but also to various physical training contexts.

Afterward, I reused the segment history produced by a dance teacher to propose a new practice schedule to dance students (study 5). Using

this principle, I set up a structured observation to compare two tasks: self-scheduled learning versus teacher-scheduled learning. Through structured observation, I was able to apply rigorous principles of experiment design to qualitative observational data. My goal was to explore the difference between these two tasks and generate new design directions. Structured observations provide the possibility to takes advantage of experiment design principles to compare qualitative data in a systematic way. It allows me to explore and generate new insights on using segment history to create learning schedules and a new way of teaching dance.

However, I also acknowledge the limitations of structured observations. In study 5, I compared dancers' segment history and found similar segmentation strategies between dancers, such as regrouping segments to focus on transition and the big picture or un-grouping segments to focus on specific details. The fact that a tendency can already be observed with a limited number of dancers is promising. However, the amount of data collected in the workshops was too limited to analyze further segmentation patterns. Especially, understanding how dancers segment dance videos is still an open research question [deLahunta and Barnard, 2005] closely linked to expertise and motor learning [Zacks and Swallow, 2007, Bläsing, 2015]. I believe that the results of study 5 would benefit from a larger sample of dancers' segmentation in order to find alternative segmentation patterns. *MoveOn* is suitable to study video segmentation with a larger scale of users, offering a web multi-platform interface to log user actions and segments.

7.2 Supporting dance learning with artifacts

I found that in both individual and collective learning, dancers produced artifacts to analyze the choreography. Moreover, artifacts play an important role in knowledge sharing. Kirsh argues that producing artifacts is a fundamental part of the thinking process: artifacts enhance cognitive power, are useful to understand and interact with complex structures, facilitate representation, and share thoughts [Kirsh, 2010]. Stahl et al. [2014] argue that artifacts save a trace of the collaboration process in collaborative tasks. I add that artifacts reveal users' learning process, individually and collectively. Precisely, when dancers create artifacts, they embed their expertise, vocabulary, and viewpoint in it. During learning, dancers' vocabulary and expertise evolve over time and artifacts do not necessarily follow these changes. This is why some artifacts are abandoned, others are re-appropriate.

Some appear early in the learning process, others later. Ecologically valid methods and longitudinal studies are crucial to understanding changes that occur in learning over time. Moreover, designing for learning requires to build interactive tools that can adapt to changes and role shifting over time.

In the context of dance making, Ciolfi Felice et al. [2016a] observed that choreographers also use drawings, texts, diagrams, or videos to represent and structure their ideas [Delahunta et al., 2004]. They call them *Choreographic objects*. These artifacts created by choreographers have an important pedagogical value for dancers willing to learn a dance piece because they reveal the choreographic structures as imagined by the choreographers. However, when the piece is finalized, in most cases, the choreographic objects disappear. I found that the rehearsal director in the longitudinal study preserved some of his old artifacts and shared them with the dancers. An important aspect of transmission is making these artifacts last and transmitting them between dance practitioners.

The artifacts created by the dancer have the role of visualizing and making persistent choreographic ideas. Indeed, some choreographic rules are opaque to an observer who only has access to dance videos. The choreographer William Forsythe, understood this problematic and created his *Improvisation Technologies* CD-ROM [1]. With Chris Ziegler, Forsythe added geometric shapes to make visible elements of his improvisation. It allows the choreographer to refer to visible concrete objects and support his explanations [Forsythe and Sommer, 1999]. Choreography support tools by preserving and reifying artifacts created by choreographers can become powerful dance learning tools. Dancers should be able to appropriate and interact with choreographers' ideas to better understand their philosophy and the structures underlying their pieces. Moreover, this tool serves to make choreographic objects last to transmit it to other generations.

[1] https://www.youtube.com/user/GrandpaSafari

7.3 Saving traces of the learning process

The idea behind *MoveOn* was to capture the traces of the learning process in order to study techniques and strategies that dancers use to learn.*MoveOn* is based on the process of reification: "*the process of turning user actions into first-class objects that act as tools*". In *MoveOn*, a segment reifies the concept of segmenting and provides the possibility to manipulate video through interactive objects, i.e. segments.

Gustafsson et al. [2020] showed how the reification principle allows to make persistent traces of activity that would be otherwise lost. Similarly, the segment history is the reification of the action of creating a history of segments. The segment history becomes a tangible object that can be reused and shared to teach dance (study 4).

Saving traces of past activity is a common feature of physical training applications, such as running apps. Woźniak et al. [2015] argue that runners with running apps now have access to extensive data about their physical activity. One of the common features of running apps [2] is capturing and saving traces of runners' race using a position tracker technology (GPS). However, Woźniak et al. [2015] describe that a common problem for runners is to reflect on their past race performances. They argue that the lack of interactivity with running traces does not help runners in recalling and ameliorate their experiences. With *MoveOn*, the segment history saves an interactive trace of dancers' previous segmentation. Dancers can replay each segment, read annotations, and access an overview of their segmentation over time. Such interactivity enables dancers to recalls their segmentation process. Adding interactivity to traces of past activity is essential not only for capturing dancer's experience, but also to let users explain and reflect on their activity.

[2] Addidas running, Strava, TrailConnect, Etc.

8

Conclusion

In this thesis, I explore how to design interactive tools to support and understand dance learning from videos in both individual and collaborative settings. I was particularly interested in capturing implicit processes embodied in real dance practices.

I initiated the thesis with semi-structured interviews with contemporary dancers and made them verbalize their learning process. I found that dancers engage in a set of highly varied strategies to learn dance phrases that we called learning techniques: segmentation, imitation, repetition, adaptation, mental simulation, and marking movements. Based on the results of these interviews, I conducted an observational study in a dance studio where I asked dancers to learn a dance choreography from a video and report on their process with documentation materials. Although I highlighted the idiosyncratic nature of the learning process, I was able to identify the video segmentation process as an embodied knowledge that structures dancers' learning (empirical contributions). From these two studies, we derived a set of implications for the design of tools to support and understand embodied knowledge appearing during dance learning: "Support personalization of learned movement", "Extract implicit movement variations and make them explicit", "Provide a palette of tools based on learning techniques", and "Save a tangible trace of the learning process" (empirical contributions).

From the design implication, I designed an interactive tool that reifies the action of segmenting and repeating video clips into interaction

techniques (design contributions). I implemented *MoveOn*, a technology probe that allows dancers to segment dance videos into interactive segments and save a trace of this process (technological contributions). I conducted a workshop with six dancers and asked them to learn a dance choreography on video using *MoveOn*. The dancers were able to segment and repeat specific video clips while learning. The systems saved all the dancers' segments in a segment history, offering a tangible trace of their segmentation process (empirical contribution). Segment histories allowed dancers to explain and reflect upon their segmentation process in a group discussion, more concretely than with interviews and observations (empirical contribution). The segment history served as an effective analysis tool to identify the changes in focus and understand dancers' segmentation strategies. I identified two segmentation strategies: Dancers *regroup* a set of segments into a larger one to focus on the big picture and transitions, or *ungroup* large segments into shorter ones to focus on details and problems (empirical contributions). Based on the results of the previous group discussion, I envisioned *MoveOn* as a teaching tool. I examined the possibility to share and reuse a segment history in a structured observation. I compared two learning tasks: dancers learning with their segmentation versus learning with a segmentation created by a teacher. The results suggest that the teacher-created segmentation is an effective tool to support the learning of novice dance students (empirical contribution). Through this study, a question remained, how learning occurs in a more collective context.

Although dance learning is a personal process, it is also collaborative and impacted by the group's activity. In my last study, I focused on the collaborative and distributed aspect of dance learning. I started a collaboration with a dance company engaged in the restaging of a dance piece. Over a longitudinal study, I gathered and studied the creation and the use of a massive amount of digital and physical artifacts (methodological contribution). By studying these artifacts, I showed how dancers created compilation platforms to share and distribute their artifacts to the group, promoting a shared memory. I also showed how artifacts act as tools to decompose, simplify, isolate, and focus on different choreography aspects. Finally, I describe how dancers develop expertise on specific parts of the choreography and how they turn to be referent dancers for the group: Memory is distributed not only through an ecology of artifacts but also within the dancers' bodies. This study proves that these artifacts offers a rich source of design opportunities for tool makers seeking to support dance learning's collaborative aspect (empirical contributions).

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université PARIS-SACLAY
ÉCOLE DOCTORALE
Sciences et technologies de l'information et de la communication (STIC)

Titre: Capturer l'apprentissage du mouvement de danse

Mots clés: Apprentissage, Interaction Incorporée, Interaction Humain Machine, Partenariat Humain Machine, Danse, Segmentation

Résumé: Cette thèse porte sur la conception d'outils interactifs pour comprendre et faciliter l'apprentissage de la danse à partir de vidéos. Les processus d'apprentissage des danseurs représentent une source d'informations riches pour les chercheurs qui s'intéressent à la conception de systèmes soutenant l'apprentissage moteur. En effet, les danseurs experts réutilisent un large éventail de compétences qu'ils ont appris. Cependant, ces compétences sont en partie le résultat de connaissances implicites et incarnées, qui sont difficilement exprimables et verbalisables par un individu.

Dans cette thèse, je soutiens que nous pouvons capturer et sauvegarder une trace des connaissances implicites des danseurs et les utiliser pour concevoir des outils interactifs qui soutiennent l'apprentissage de la danse. Mon approche consiste à étudier différentes sessions d'apprentissage de danse dans des contextes réels, aussi bien individuels que collaboratifs.

Sur la base des résultats apportés par ces études, je contribue à une meilleure compréhension des processus implicites qui sous-tendent l'apprentissage de la danse dans des contextes individuels et collectifs. Je présente plusieurs stratégies d'apprentissage utilisées par des danseurs et j'affirme que l'on peut documenter ces stratégies en sauvegardant une trace de l'apprentissage. Je discute de l'opportunité que représente la capture de ces connaissances incarnées et j'apporte de nouvelles perspectives pour la conception d'outils d'aide à l'apprentissage du mouvement par la vidéo.

Title: Capturing traces of the dance learning process

Keywords: Learning, Embodied Interaction, Human-Computer Interaction, Human-Computer Partnership, Dance, Segmentation

Abstract: This thesis focuses on designing interactive tools to understand and support dance learning from videos. Dancers' learning practice represents a rich source of information for researchers interested in designing systems that support motor learning. Indeed, dancers embody a wide range of skills that they reuse during new dance sequences learning. However, these skills are in part the result of embodied implicit knowledge.

In this thesis, I argue that we can capture and save traces of dancers' embodied knowledge and use them to design interactive tools that support dance learning. My approach is to study real-life dance learning tasks in individual and collaborative settings.

Based on the findings from all the studies, I discuss the challenge of capturing embodied knowledge to support dancers' learning practice. My thesis highlights that although dancers' learning processes are diverse, similar strategies emerge to structure their learning process. Finally, I bring and discuss new perspectives to the design of movement-based learning tools.

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