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# UX design for memory supplementation to support problem-solving tasks in analytic applications

Lingxue Yang

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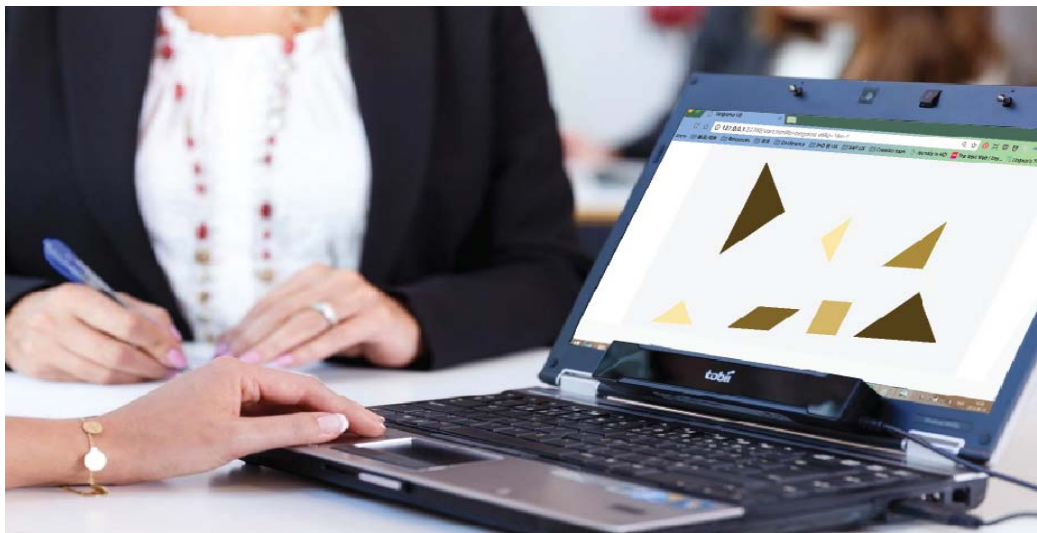
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Par Lingxue YANG

*UX design for memory supplementation to support problem-solving tasks in analytic applications*

Thèse présentée  
pour l'obtention du grade  
de Docteur de l'UTC



Soutenue le 12 décembre 2018

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Laboratoire Heudiasyc - UMR CNRS 7253  
Laboratoire Costech – EA 2223

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# UX design for memory supplementation to support problem-solving tasks in analytic applications

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Par Lingxue YANG  
Pour obtenir le grade de  
**DOCTEUR** de L'Université de Technologie de Compiègne

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**Date de soutenance** : 12 décembre 2018

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## ABSTRACT

This thesis was initiated in the context of enhancing the user experience for analyzing data due to the increase of the volume of data related to this activity. On the one hand, users' psychological needs for the simple use of analytic applications are paid more attention than before; on the other hand, the task they are willing to conduct is getting more and more complicated, which may cause memory overload that influences the task performance. To ensure that both aspects are taken into account, the designers should provide a proper information and design a proper interface that meets both users' needs and the requirements of their activity. In this research, we are interested in improving the task recommitment following a task suspension or interruption in the context of a visual data analysis task. The multitasking nature of user actions and limited storage capacity of human working memory cause difficulties in re-engaging an interrupted or suspended task. Therefore, it is beneficial to have a memory supplementation tool that supports users to recommit their task in optimal conditions.

A literature review first leads to the positioning of our research on the enactive approach and sensorimotor perception that consider the tool as an artifact configuring the interaction between the user and the task, in two modes the "put down" mode and the "in hand" mode. From this point of view, we have found that the commonly used cognitive memory model ignores the role of interaction with the external world in the formation of the memory, and consequently ignores the "in hand" dimension of the artifacts in one memory construction. Therefore, we complete this model with the embodied memory, which gives us a new perspective to design an appropriate memory tool that serves as a supplementation of our perceptual system. Finally, the design principles in human-computer interaction and UX helped us build a tool and conduct an experimental plan highlighting the link between changes in perception conditions and changes in the dynamics of interaction. As a conclusion, the research problem is introduced in terms of how we can provide users with a relevant context to recommit to resolving a task after interruption. The design proposal needs to be explored, designed and evaluated.

The first experiment, the exploratory study, analyzes the perception of interactive applications by experienced designers. This study helped us construct a vocabulary of evaluation of the design for a memory supplementation support and guided us for the design considering these criteria.

In the second experiment, we develop a tool based on a function that we call the "history path", which permits to show, in a specific window of the user interface, some of the steps of a previous task resolution that a user has performed during previous experience (or to simulate a resolution task interruption). We set up a simple (minimalist) experiment simulating a problem-solving task, which was recorded to evaluate the extent to which a history path support can help the user for efficient recovering of an interrupted task. The first part of this experiment allows us to confirm the potential use of this function and helps us explore the design space. In the second part, we experiment two different tools, based

on two history path representations, a static one and a dynamic one. The evaluation results allow us to understand the technical conditions of a positive experience for which task recovery is facilitated. In this second experiment, several means for recording the user experience were mobilized: the evaluation of the durations and gaze frequencies on area of interest in the interface window by eye tracking, the recording of the verbalizations during the RTA (Retrospective Think Aloud) session, and the semantic evaluation.

We consider that the results are transposable to similar design issues in a digital environment. We also apply this concept in a professional analytic application: SAP Analytic Cloud. A prototype was built for this research purpose. The feedback and suggestions from the UX designers who were asked for an initial assessment of the proposal are quite positive and open up perspectives for in-depths analysis and development in the future.

To conclude, this research work proposes a new research method mobilizing a technological approach with the creation of a prototype from which the research questions arise, and knowledge emerges. Our research shows the necessity and possibility of memory supplementation for task recommitment in the context of task interruption. A new avenue of investigation could raise the question of time, and the question of modifying the perception of time and the dynamics of interaction by modifying the conditions of interaction of the "in hand" interface.

Keywords: Memory Supplementation, Interaction Design, User Experience (UX), History Path, Sensorimotor Perception

## RÉSUMÉ

Cette thèse a été initiée dans un contexte d'amélioration de l'expérience utilisateur (UX) pour l'analyse des données de Business Intelligence en raison de l'augmentation du volume de données liées à cette activité. D'une part, les besoins psychologiques des utilisateurs portent sur la simplification de l'utilisation des applications analytiques, ils font l'objet de plus en plus d'attention ; d'autre part, les tâches qu'ils sont prêts à mener deviennent de plus en plus complexes ce qui peut entraîner une surcharge de mémoire qui influe sur les performances dans leur réalisation. Pour garantir la prise en compte de ces deux aspects, les designers doivent concevoir des interfaces et fournir des informations appropriées qui répondent à la fois aux besoins des utilisateurs et aux nécessités de leur activité. Dans cette recherche, nous nous sommes intéressés à l'amélioration de la reprise de la tâche suite à une suspension ou à une interruption de celle-ci dans le cadre de l'analyse visuelle de données. La nature multitâche des actions des utilisateurs et les capacités limitées de stockage de la mémoire de travail humaine entraînent des difficultés à s'engager de nouveau dans une tâche qui a été interrompue ou suspendue. Il devient donc avantageux de disposer d'un outil de suppléance de la mémoire qui aide les utilisateurs à se remettre à leur tâche dans des conditions optimales.

Une revue de la littérature nous a conduit tout d'abord au positionnement de notre recherche vis à vis de l'approche énaïve et de la perception sensorimotrice qui considèrent l'outil comme un artefact configurant l'interaction entre l'utilisateur et la tâche, selon deux états, saisi ou déposé. De ce point de vue, nous avons constaté que le modèle de mémoire cognitive utilisé couramment ne considère pas le rôle de l'interaction avec le monde extérieur dans la construction de la mémoire, et par conséquent ignore la dimension saisie des supports et outils dans la construction d'une mémoire. Par conséquent, nous proposons de compléter ce modèle avec un modèle de mémoire incarnée, qui ouvre une nouvelle perspective permettant de concevoir un outil de suppléance mémorielle approprié. Enfin, les principes de conception d'IHM et d'UX nous aident à construire une proposition d'outil et à mener un plan d'expérience mettant en avant le lien entre les modifications des conditions de perception et les modifications de la dynamique d'interaction. En conclusion de cette partie, la problématique générale est introduite avec l'exploration, la mise en œuvre et l'évaluation de la proposition.

La première expérience, le test pilote, analyse la perception que peuvent avoir des concepteurs naviguant sur des applications interactives. Cette étude nous a aidé à construire un vocabulaire d'évaluation en conception d'un support de suppléance de la mémoire et nous a guidé pour concevoir un processus expérimental en tenant compte de ces critères.

Dans une seconde expérience, nous développons un outil basé sur une fonction que nous appelons le "*history path*". Cet outil permet d'afficher à l'utilisateur, dans une fenêtre spécifique de l'interface, certaines étapes de résolution d'une tâche antérieure effectuée par ce même utilisateur (ou pour simuler une interruption de tâche). Nous avons mis en place une expérience simple (minimaliste) simulant une résolution de problème qui a été enregistrée pour évaluer dans quelle mesure le *history path* peut aider l'utilisateur à récupérer efficacement une tâche interrompue. La première partie de cette expérience nous



permet de confirmer l'utilité potentielle de cette fonction et nous aide à explorer l'espace de conception. Dans la deuxième partie, nous expérimentons deux outils différents basés sur deux représentations de l'*history path*, une représentation statique et l'autre dynamique. Les résultats de l'évaluation nous amènent à comprendre les conditions techniques d'une expérience positive pour laquelle la reprise de tâche est facilitée. Dans cette seconde expérience, plusieurs moyens d'enregistrement de l'expérience utilisateur ont été mobilisés, l'évaluation des durées et fréquences de regard sur des zones d'intérêt de l'interface par eye tracking, l'enregistrement des verbalisations lors de tests RTA (Retrospective Think Aloud) et l'évaluation sémantique.

Nous considérons que les résultats sont transposables à des issues similaires dans un environnement numérique et nous expérimentons l'application de ce concept dans une application analytique professionnelle : *SAP Analytic Cloud*. Un prototype a été construit uniquement à cette fin de recherche. Les retours d'expérience et les suggestions des concepteurs d'UX qui ont été sollicités pour une première évaluation de la proposition sont plutôt positives et ouvrent des perspectives d'analyse approfondie et de développement dans le futur.

En conclusion, ces travaux proposent une nouvelle méthode de recherche mobilisant une démarche technologique avec la création d'un dispositif par lequel des questions de recherche se posent et des connaissances scientifiques émergent. Notre travail montre la nécessité et la possibilité d'une suppléance mémorielle pour le réengagement dans des tâches suite à l'interruption de tâches. Une nouvelle piste d'investigation pourrait porter sur la question du temps et sur la question de la modification de la perception du temps et de la dynamique d'interaction par la modification des conditions de l'interaction de l'interface saisie.

Mots-clés : Suppléance de la Mémoire, Design D'interaction, Expérience Utilisateur (UX), History Path, Perception sensorimotrice



*This thesis is dedicated to*

*My parents*

*&*

*my grandmother,*

*Thank you for your unflinching support and wealth of love.*



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## GLOSSARY

Analytic provenance	Analytic provenance is the research that “focuses on understanding a user’s reasoning process through the study of their interactions with a visualization system”.
Business intelligence (BI)	The set of techniques and tools for the transformation of raw data into meaningful and useful information for business analysis purposes. BI process is about taking data and transforming them into information, which gives the end-user insight to make a decision that brings value.
Dashboard	A dashboard is a single screen in which various critical pieces of information are placed in the form of panels. Some of the information that may be contained on a dashboard including reports, web links, calendar, news, tasks, e-mail, etc.
Data visualization	It’s a more or less a holistic representation of quantifiable information abstracted into a schematic form to assist users in better understanding what the data are telling them. The generation of the Data Visualization elements is basically scientific and are generally handled by software. These usually take the form of graphs, maps or charts.
Dimension	A multidimensional structure which represents a side of a multidimensional cube. Each dimension represents a different category, such as region, time, and product type.
Experience map	An experience map is a visualization of an entire end-to-end experience that a “generic” person goes through in order to accomplish a goal.
Filter	A mechanism that includes or excludes specific data from reports based upon what the user decides to filter (e.g., to tightly tailor a report, you may strictly want records of customer.
Key Performance Indicator (KPI)	<p>These indicators are measures that are important to the business, typically relating to the overall health of its operation. The results are reported in the form of a <i>dashboard</i> or a <i>scorecard</i> report that enables executives, managers, and employees to assess performance, and whether a given goal (or metric) is being met, exceeded, or missed.</p> <p>An example would be profit margin. Profit margin can be trended over time. A significant deviation (for the worst) from expected values can alert management to drill into</p>



those measures of profit margin to see which the cause of the issue may be, calling for a quick response.

Line of business	Line of business often refers to an internal corporate business unit, whereas the term "industry" refers to an external view that includes all competitors competing in a similar market. For example, sales, marketing, finance, HR, supply chain, IT, etc.
Measure	Numerical data stored on a fact table is a measure. For instance, regarding sales fact, we might have a measure for cost, gross profit, maybe even order fulfillment time. These measures can then be summarized for each level of analysis.
Persona	A persona is a user archetype, a fictional individual derived from real users, needs, preferences, biographical information, and a photo or illustration. It helps a development team to empathize with user (Alan Cooper).
Reporting	Reporting means collecting and presenting data so that it can be analyzed.
Retrospective think aloud (RTA) protocol	Retrospective thinking-aloud (RTA) protocol is a form of think aloud and used in eye tracking test in particular. It is performed after the user testing session activities, instead of during them. Fairly often the retrospective protocol is stimulated by using a visual reminder such as a video replay, called cued RTA.
Self-service BI	An approach to data analytics that enables business users to access and work with various information without the information technology (IT) involvement (except, of course, to set up the data warehouse and data marts underpinning the business intelligence system and deploy the self-service query and reporting tools).
Tangram	Tangram is a Chinese puzzle consisting of seven flat shapes, which are put together to form shapes. The objective of this puzzle is to use all the given shapes to build a specific shape without overlapping each other.
Think aloud protocol	Think aloud protocol is a dominant method to gather data in usability testing in product design. Think aloud protocol involves participants talking about whatever comes into their mind (looking at, thinking, doing and feeling) as they are performing a set of specific tasks.
Usability	The extent to which a system, product or service can be used by specified users to achieve specified goals with

effectiveness, efficiency and satisfaction in a specified context of use (ISO 9241-11, 1998).

#### User experience (UX)

According to ISO 9241-210, user experience refers to a person's perceptions and responses resulting from the use and/or anticipated use of a product, system or service. User experience includes all the users' emotions, beliefs, preferences, perceptions, physical and psychological responses, behaviors and accomplishments that occur before, during and after use. Different definitions are presented in chapter 3.



# CHAPTER 1 INTRODUCTION

*"Products were once designed for the functions they performed. But when all companies can make products that perform their functions equally well, the distinctive advantage goes to those who provide pleasure and enjoyment while maintaining the power. If functions are equated with cognition, pleasure is equated with emotion; today we want products that appeal to both cognition and emotion."*

— Donald A. Norman, American scientist

*"Simplicity is about subtracting the obvious and adding the meaningful."*

— John Maeda, American designer, *The laws of simplicity*

This research is an interdisciplinary work involving cognitive science, human-computer interaction (HCI) and analytics. The tremendous growth of data stored in software applications brings both opportunities and challenges for analyzing large dataset. As a response to this demand, a growing amount of analytic applications<sup>1</sup> propose to help users with advanced visual analytics capabilities. The interaction between the human and the computed intelligence has acquired an unprecedented attention than ever, aiming at improving the user experience. However, as analytic process becomes more and more complex, business users are still spending a lot of time exploring, analyzing data, creating storyboard and sharing (explanation) with their peers. Users' expectation of simple operation compared to complex data analysis process are the new challenges held by designers. As the carrier of the interaction between human and information, the user interface is a key part that influences the systems and human performance. Therefore, we should consider the context of use, characteristics of the analytical task and the user' expertise to improve the process of designing this kind of applications. An improper information and interface design hinders users' understanding, learning and use of the interactive systems, causing cognitive barriers, such as memory overload. We are specifically interested in the user experience as a whole of the consequence of the interaction, and it is around this theme that our design objective is articulated.

In this chapter, we present the research context that flows between user experience and analytics, some key elements of the industrial context, which drives the motivation of this

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<sup>1</sup> Analytic applications are packaged business intelligence (BI) capabilities for a particular domain or business problem – [Gartner IT glossary](#). In the following texts, we use BI applications and analytic applications interchangeably.

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research, from both of which we can outline a first draft of the general problem that we will address as well as a roadmap of this thesis plan.

## 1.1 RESEARCH CONTEXT

In recent years, the advances made in computer technology have made human-computer interaction (HCI) penetrated into almost all areas of human activities. The technological context is extremely favorable to the emergence of design and usability researches. The design focus has been successively transferred from the first effort of functionality-oriented (to facilitate the access to information systems for specific users) in the 1970s, to considerable advances in the areas of usability<sup>2</sup> in the 1980s and 1990s, to the consideration of users' psychological needs (i.e. emotions) from the 2000s (Brangier, Hammes-Adel , & Bastien, 2010; Mayhew, 2008). Over the years, users have taken an increasingly central place in the design process.

In traditional design, the product's function was closely related to the product's physical form such as material, structure and so on. It was easy for users to understand its functions through this physical form. However, in the information age, the digital products are not constrained to tangible forms and functions but extended to some intangible contents. More importantly is the way of information communication between human and system and its formal elements that express the interaction. Therefore, it is not merely a matter of aesthetic issues, rather it is a combination of user cognitive factors and the logical process of information systems (Cooper, Reinmann, & Cronin, 2007). Especially in the case of business software, such as analytic applications, behind which there are sophisticated logical reasoning.

BI and analytic applications are the tools that enable the transformation of data into information, which gives the end-user insights to make a decision and take an action that brings value. These applications are also called decision support systems (DSS) (Power, 2007). The users may be operational users who consume the results of analysis (called business users) or analysts from different line of business who conduct the analysis, such as business experts (i.e. human resources, sales, marketing). In the BI and analytic application, users need to analyze multi-dimensional data from multiple perspectives. For example, in a database model of sales, it consists of dimensions navigation and measures. The measures are numerical data such as sales revenues, margins, budgets, profits, etc. They are categorized by dimensions used to group the data, which is roughly similar to the "group by" operator. Typical dimensions are regions, countries, time (year, quarter, month, etc.), product (see Figure 1). The two salient features of the BI applications are: integrate the queries' output from the database multiple queries and represent it by the means of visualization supports (charts, reports, storyboard, etc.).

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<sup>2</sup>Usability: the extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use (ISO 9241-11, 1998).

# INTRODUCTION

Dimensions				Measures							
Time	Geo	Product	Manager								
Year	Region	Product Line	Manager	Quantity sold	Sales Revenue	Gross Margin	Discount	GMR	Customer Satisfaction	Number of Issues reported	
Quarter	Country	Product Category									
Date	City	Name									

Figure 1. Example of the dimension and measure of a dataset for analysis. Time is organized in hierarchy year – quarter – date so as to Geo and Product.

Historically, it was experts (called data analysts) who used the BI and analytic applications to analyze data and build reports. With the increase of need of data insight to trigger operational decision in multiple areas (HR, finance, marketing, ...) and a better access to analytic applications, more business users are demanding to autonomous in the data analysis activities but with less expert knowledge. They often do their data analysis tasks through interactive visual interfaces combining different data visualization techniques corresponding to different data analysis process (see Figure 2). Data visualization provides an easy-to-understand way to summarize the main characteristics of a dataset, which facilitates faster and more focused analytic process (Tufte, 2001).

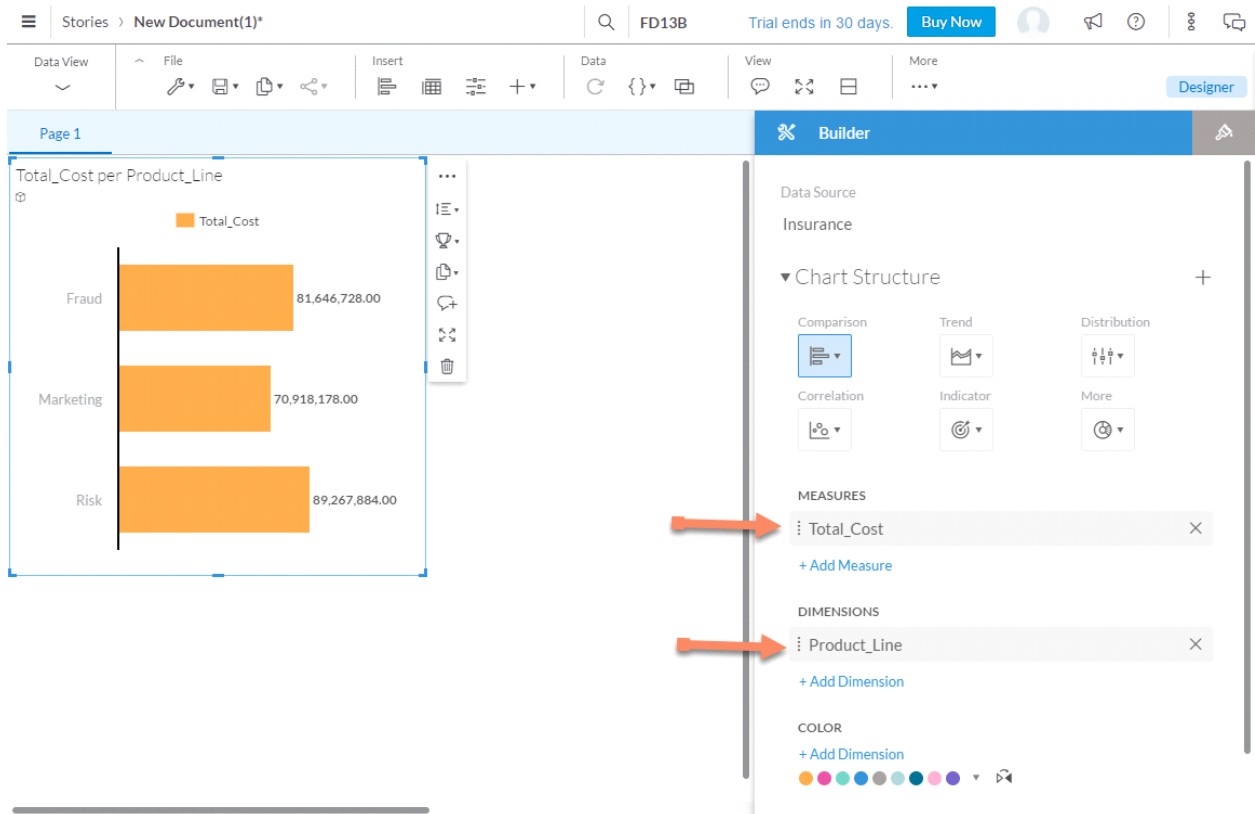


Figure 2. Data exploration – adding charts to visualize data (image from SAP Analytics Cloud)

The big data revolution has made large amounts of data available to use for discovering insights for business. However, they are becoming more complex and less structured. This, on the one hand, increases the complexity of analytic applications, which needs rich functionalities, and on the other hand, promotes the users' expectation of intuitive interaction and access to the appropriate data for analytical tasks. Therefore, there is a big challenge between the users' expectation of intuitive interaction and sophisticated analysis functions.

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Traditionally, the design of interactive systems focuses on the instrumental aspects (functionality and usability). The design community have been making much effort on the user interface (UI) design of the software to provide a simple to use product. This approach remains widely used even in today's software design. However, people strive for something more once they get used to having something (Maslow, 1943). Analytics users want more from a system than simply "ease of use" (Carroll, 2013). Translating from Maslow's hierarchy of human needs, Jordan (2000) and Walter (2011) both proposed, for designing products, to consider the needs of users as functionality, usability and pleasure. This means that if a product is not usable if it does not meet the functional requirements, and once it has the appropriate functionality, it is expected to be easy to use. Having had functionality and usability, people desire more from products, expecting not only instrumental benefits but also non-instrumental and emotional ones as "living objects".

Therefore, in today's analytic applications, users are not satisfied by just efficient task completion, but rather call for a full range of user experience (UX) of interaction with interactive systems (Mahlke, 2008a). The analytic applications serve as a medium, which enables users to establish their own experience with a world materialized in data. This research work has been significantly inspired by the design environment of analytics research and development (R&D) practice at SAP. As a major actor of the radical change in the human-technology relationship, SAP, the market leader in enterprise software, initiated this research to leverage the impact of user experience toward a functional simplification of big data usage.

## 1.2 INDUSTRIAL CONTEXT

This thesis is the result of the cooperation between the university of technology of Compiègne (UTC) and SAP (Systems, Applications and Products for data processing) under a CIFRE agreement (Conventions Industrielles de Formation par la Recherche). SAP, founded in 1972, is a world leader in enterprise applications, analytic applications and software-related services.

SAP offers an extremely varied range of software, which includes: business process solutions, and analytic applications. Business process solutions involve a software portfolio enabling customers to improve their business processes, such as ERP (enterprise resource planning), which supports the daily operations management (e.g., human resources, customer relationship management). Analytic applications with business intelligence (BI) capabilities enable easier access to all enterprise data, supports analysis activities and thus provides an opportunity to make relevant decisions based on the information describing a situation. SAP delivers a broad range of BI capabilities for both large IT-managed enterprise reporting deployments and business-user-driven data discovery deployments (Gartner, 2017). These analytic applications include traditional reporting tools, such as Web Intelligence, Design Studio, Crystal Reports, etc. and visual-based data discovery tools, such as SAP Analytics Cloud, Lumira (See *Figure 3*).

## INTRODUCTION

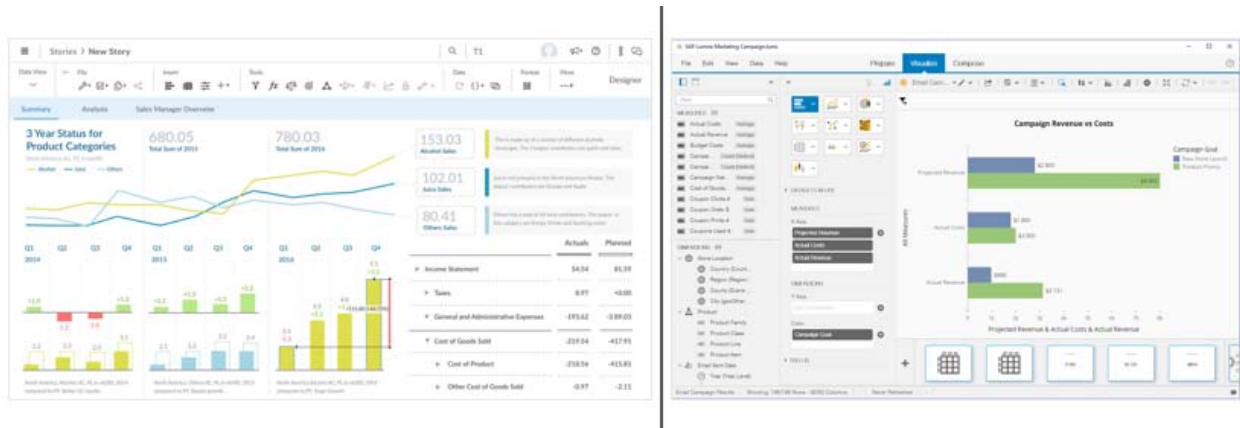


Figure 3. SAP Analytics Cloud & SAP Lumira

This PhD research takes place in an SAP research department specialized in the user experience (UX) design for analytic applications. It was initiated as a result of the radical change in the human-technology relationship to meet the users' needs in the most useful, usable and desirable way to increase user satisfaction, customer loyalty and strengthen relationship between IT and business. The product and service quality especially their usability are nowadays crucial differentiators. This marks a strong shift from business strategy to spread SAP's innovation that focuses on business, technology and people. In addition to technological innovation (cloud computing, in-memory database), SAP involves user-centered approach and focuses on the interaction with technology, which empowers users and the way they work. Innovation in interfaces and interaction modalities focuses on the quality of the "use experience" offered by the product:

"The interaction with the product should contribute to the overall pleasure found in the function of the product itself. The experiential is assumed to lead to joy of use." (Overbeeke, Djajadiningrat, Hummels, & Wensveen, 2000)

The mission of the UX designers at SAP is to drive user-centered design in order to imagine software that enables the user to achieve complex tasks in a simple way and thus optimize the user's productivity and satisfaction. UX design in this context aims at supporting the cognitive process of analysis and decision-making.

In addition, it is a trend that the BI and analytic platform market shift from IT-led reporting to modern business-led analytics according to Sallam et al. (2017) in Gartner report on business intelligence and analytic platform. The latter one, self-service BI and analytics, emphasizes the easy-to-use tools to support a full range of analytic workflow capabilities without significant IT involvement in order to make decisions and identify insights for business. As market leader, SAP, is driving the change expanding its BI solutions from traditional to self-service. With a deep design thinking approach spread across the company, SAP is constantly developing the innovative and creative prototypes today to dominate tomorrow's analytics market.



## 1.3 GENERAL PROBLEM

As mentioned above, the designers are facing new challenges. An increasing number of business users, who do not have technical background, expect to have an easier control on the report they have to build and manipulate, particularly in the case of data visualization, to identify the root causes of the phenomena depicted by data or to discover some insights in order to make a proper decision. Self-service BI is coming out to meet this new requirement. However, a traditional BI application has many rich functions, which require high level skills. Moving from the traditional BI to self-service BI requires a great amount of usage simplification. Besides, some of the products target decision makers, who rather consume the reports without BI background as well as data analysts whose main work is BI. They have to satisfy different types of users, considering their different expertise and context of use. However, what an expert can do easily in the system may be difficult to a novice.

During our research, we observed recurrent problems usually encountered in the usage of self-service BI applications from a competitive analysis and a discussion with the designers in SAP UX team:

- *Technical issue:* in handling, large datasets and depending on the IT infrastructure in place, analytic tools are relatively slow in performance. The users have to wait seconds to do an action, which causes frustration.
- *Usability issue:* for novice users, some information is confusing and hard to understand, some functions are not easily to find (visible), the icon is not clearly presented, etc. All these usability issues influence users' task performance and may cause negative emotions. In addition, users expect more interactions on the data visualization.
- *Working memory overload:* in visual analytic tasks, the user's main task is to acquire the useful information that allows him/her to identify the root causes of a business question for decision making. It requires a large number of storages of human working memory to process the information needed for completing an analytical task. As the working memory is limited in capacity, not all the information can be stored in once. Our working memory only stores the most recent information for the current activated task. One consequence is that when the task is interrupted or suspended, to handle a secondary task (interrupting task), the working memory will free up some space for processing the information needed for this secondary task. When the user returns to the primary task (interrupted task), he/she has to recall the released information. It takes time, overcharges the working memory and consumes much mental effort from the user. The result is the loss of time, and reduced task performance. Tracking the history becomes a barrier for exploration and commitment.
- *User's expertise:* As more business users are involved in the role of data analyst, their need to use the BI applications is increasing. However, a lack of data analysis expertise causes a large gap between the users' simple interaction and complex BI

## INTRODUCTION

system. Due to this, the users lack motivation to conduct a complicated analysis, they use the tools' functions insufficiently. This calls for taking the user's roles into account and their context of use.

Apparently, the above problems are not limited to usability issues in the current usage of analytic applications but are linked to a wide range of the context of use, cognitive process of users, memory, emotions, etc. We must start from understanding users including their goals, tasks, needs, etc. so as to establish user mental model among the above problems. We are thus interested in the working memory overload issue in the analytical process, which is a fundamental question related to human cognition and user interaction. Particularly, we have noticed that there is a great gap between human cognition and user interface design. It may cause an obstacle for the user to explore and use the tools. It is thus necessary to take this into account for the design of tools for analytics. There are still questions that remain to be clarified before we are able to formulate this research problem.

1. How do users use information?
2. How does the memory work, particularly in the task of problem solving?
3. How can we take into account the memory parameters in the design of the interface?
4. How can we build a lived experience to engage the user in solving the task?

These questions are related to the design of the user interface, as a media between the user and the analytic task, to provide a positive user experience. In this research, we try to pose a problem, which may improve considerations in providing a new idea and method to design analytic applications for resolving the imbalance between user interface and human cognition. There is a close relationship between human cognition and the design and evaluation of the user interface. The evaluation of the user interface can reveal the user's perception of the system and the result of this evaluation can assist design as well. It is important to understand human's cognitive process for improving user experience.

To begin with, we need to conduct a literature review related to these questions, through which we aim at formulating our research problem for harmonizing human cognition with user interface.

## 1.4 OBJECTIVE AND PLAN

### 1.4.1 OBJECTIVE

This research project is of fundamental interest for the company because of a strong industrial challenge, but it also addresses academic interests. This work follows a user-centered design approach to enhance the user interaction in relation with his or her emotional experience and address the challenge in the case of analytic applications. We are mainly interested in the visual data analysis part, which enables users to work in a more self-service oriented way with less IT involvement for their every dashboard, report and other visual artifacts. Our research work is carried out in the theoretical and methodological

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perspectives of Human-computer Interaction. However, we are interested in the entire user experience as a potential means to provide answers to these problems. This implies a multi-disciplinary vision, such as cognitive mechanism (perception and memory), psychology, user experience design, etc. The objectives of this project are:

1. identify or reformulate the research problem related to the cognitive process based on the practical and theoretical method. What is probably the cause of the imbalance between cognition and user interface.
2. construct a prototype through which the problem is discovered and resolved. This prototype is aimed at transposing and applying in business applications.
3. improve the considerations in the design process. The results from the experiment can be useful for designers to create the interactions addressed to the users or future users and to evaluate an idea or an interactive task through user interface.

## 1.4.2 PLAN

We have elaborated the motivation of this thesis research in the research and industrial context and the general problem in this introduction chapter. The remaining part of this report is structured as follows in three main parts:

First part is about literature review that includes two chapters:

CHAPTER 2. Theoretical framework We first address the question human cognition in the user interaction with perceptual interfaces. We argue our choice of a theoretical framework based on the enactive approach and on the sensorimotor perception. We talk about the limitations of the traditional model of memory and propose embodied memory as another part to complete the model. And based on this, we address the research problem in the context of task interruption and recovering hoping to identify an opportunity for the design of memory aid tool.

CHAPTER 3. Instrumental framework We address the necessity of designing a memory aid tool for memory supplementation and its interaction process as a dynamic cycle of the "in hand" and "put down" mode due to the limitations of the working memory. We address the challenge that the current solution in task resumption is facing, including the history of process (analytic provenance), and task interruption effects. Then, we look at recent work in HCI and UX design, both in terms of the design methodology and evaluation method, and which aims at making the interfaces suitable for users. The positioning of this work in our design framework encouraged us to focus our research problem on a precise but crucial point for the design of interactive systems: the need to specify the conditions of technical possibility to give rise to a particular perceptive experience to users.

Second part is about the elaboration and implementation of the research method:

## INTRODUCTION

- CHAPTER 4. Research problem We are now able to reformulate our research problem based on the state of the art. We also give an overview of this research's methodology following the user-centered design approach, including an understanding of self-service BI, and SAP BI user model, which has been created based on the user types and users' intention in the company. Next follow studies of user interaction with BI and analytic applications, which were done in the company. It appears that usually, business users have to remember and recall previous interaction history for continuing an analytical task, which poses a barrier for task resumption and user engagement. The setting of a minimalist experiment as an experimental framework to study the perceptual phenomena is introduced at the end of this chapter.
- CHAPTER 5. Exploratory study An exploratory study with different design experts has been conducted to study the perception of interaction related to emotions from a professional perspective. The analysis and results are used to evaluate the setting of a second experiment.
- CHAPTER 6. Tangram experiment We investigate the importance of adding history (provenance) function in the task resolution by a minimalist experiment. We collect new findings related to the history function. We design and implement a provenance function called *history path* that is integrated in a Tangram game simulating a problem-solving task. We present a second control experiment to test if it is possible to design a tool for memory supplementation. We experiment two different tools based on two history path representations: static and dynamic. The results help us evaluate to what extent the history path can help the user for resolving the task.
- CHAPTER 7. Apply the history path framework in a professional tool We present the application of the history path in an SAP analytic application – SAP analytics cloud (SAC) and the prototype to the BI and analytic application design experts to evaluate and acquire their feedback in terms of user experience.

Third part is for conclusion and perspectives:

- CHAPTER 8. Conclusion and perspectives Finally, as a conclusion, it is an opportunity to summarize this research work and discuss a number of possible perspectives.

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# First part: literature review

*"If I have seen further it is by standing on the shoulders of Giants."*

— Isaac Newton

*"Good design is a renaissance attitude that combines technology, cognitive science, human need, and beauty to produce something that the world didn't know it was missing."*

— Paola Antonelli

The first part of this work concerns a literature review that is divided into two main chapters.

In chapter 2, we present the theoretical framework within which we want to put our work, in two parts: (1) the positioning of this research along the enactive approach and perception theory; (2) a brief overview of the role of memory in the cognitive process. It serves us to understand the limitations of the memory that will help us to think of the design of user interface. It appears that we need a tool, which can serve as a memory prosthesis or support to facilitate users to accomplish a complex task. (2) Some related works that have been done to study the problems caused by task interruption and how to recover the task.

In chapter 3, based on the problems that we identified in chapter 2, we present a state of the art in terms of the design and instrumentation: (1) the current solutions that have been proposed in the instrumentation for task recovery in the context of analytics; (2) a proposition of design for memory supplementation and the related design principles based on Norman's action model that explains the psychological process behind an action and three design principles; (3) User experience, which is beyond usability, provides a broader scope for design considerations. The study on user experience is useful for evaluating a design from all aspects of human experience rather than merely usability.



## CHAPTER 2 THEORETICAL FRAMEWORK

*"One has not only an ability to perceive the world but an ability to alter one's perception of it; more simply, one can change things by the manner in which one looks at them."*

— Tom Robbins, American author

*"When we shift our perception, our experience changes."*

— Lindsay Wagner, American actress

*"Rhyme is a mnemonic device, an aid to the memory. And some moms are themselves mnemonics, that is to say, the whole purpose of the poem is to enable us to remember some information."*

— James Fenton, British poet

### 2.1 FROM COGNITIVISM TO ENACTION

Cognitive science is the interdisciplinary scientific study of mind and mental processes, which involves how we perceive, remember, think, learn, make decisions, etc. A dominant approach in cognitive science is cognitivism that views human as an analogy of computer. It consists in the hypothesis that the cognitive system is determined and pre-defined, which forms an internal and symbolic representation of the world.

In 1967, the American psychologist Ulric Neisser published the book *Cognitive Psychology*, which states that cognitive psychology studies all the perceptual processes. This process involves the transformation, reduction, elaboration, storage, recovery, and use of various types of sensory data obtained from the environment (Neisser, 1967). This regards human mind as an information-processing system, which focuses on the information processing process of human cognition to reveal the psychological mechanisms.

In 1983, Card, Newell and Moran proposed the Model Human Processor in their book *The Psychology of Human-Computer Interaction*, which has been a theoretical basis for the study of human cognition in the field of Human-Computer Interaction (HCI) for a long time. This model divides our human processor into three subsystems: the perceptual system, the cognitive system and the motor, each with its own memories (working memory and long-term memory) and processors (Card, Newell, & Moran, 1983). Briefly speaking, humans acquire the information from their five senses (taste, sight, touch, smell, and sound), store it



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in the working memory, match it with the information previously stored in the long-term memory to make a decision, and then translate it into action. This kind of mental process is comparable to a computer software. This human activity, to some extent, is like an execution of a predetermined computer program.

An alternative to the cognitive approach, is that humans do not passively receive external information from their environment that is translated into the internal representations. The *enactive approach*, proposed by Varela, Thompson, & Rosch, (1991), views that cognition arises through a dynamic interaction between human and his/her environment. They stress that the cognitive activities do not happen without an action to be taken, thus cognition is embodied in action. Humans are autonomous in that they have the capacity to adapt to the constantly changing environment. This means that human's autonomy and its coupling with the environment bring forth the cognition. Therefore, cognition is not something that happens in our heads and is then expressed in actions but is something constructed in the adaptive interaction itself (McGann, 2007).

This enactive view is highly consistent with Lucy Suchman's view of human action in her thesis, *Plans and Situated Actions: The Problem of Human-machine Communication*. She conducted several observations of users in using a photocopier machine that is controlled by a computer-based system. The photocopier is intended to act as an "expert help system" that embraces a conception of a planning model of human actions. So, the machine shows the procedural instructions about the actions that users can take to use the machine. The observation results show that instead of following the instructions, the user constantly adapts his/her behavior according to his/her interpretation of the instructions, his/her perception of the situation and their evolution. The action of the user calls upon the available resources, not only physical facts, but also social and cultural facts, which build the situation of action. As these facts of the situation may change at any time (a new instruction of the photocopier shows up, the user discovers a new operation, etc.), the user takes an ad hoc action to adapt and adjust to the contingencies of the situation. Therefore, the user does not have time to plan his/her actions. He/she is engaged in an action and interpretation loop: the instructions help him/her understand the environment and the environment allows him/her to understand the instructions.

According to Suchman (1985), the plan is a resource for action that can be evolved rather than a blueprint of action that is static. In other words, as humans, we continually construct our plans as we go along in the situation, and we modify our next move based on what was happening. It is the interactions between human and his/her environment that determine the construction of human cognition. Perception and memory are two important parts in our cognitive process, we are going to address these two notions from an enaction point of view.

## 2.2 PERCEPTION

The enactive approach in cognitive science takes the view that the perception is the active sense-making of the interactions with the living environment. A person's action and his/her

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sensory movement patterns determine his/her perception of subjective world, and the actions eventually change the perceived world. In this process, individuals and the world are coupled together. F. J. Varela and E. Thompson built the enaction of perception on some core concepts, such as autonomy, sense-making, emergence, embodied, experience, and so on (Thompson & Stapleton, 2008; Varela et al., 1991). The enactive points of view hold the point that, first, perception is not static, it is linked to our action; second, perception is not a representation of the environment, but a fruit of *structural coupling* between the person and the world. The cognition emerges in the dynamic cycle of perception and action. Third, the perceiver's task is to generate a relational process of sense-making between the system and its environment.

(Gibson 1979, 2015) proposed the ecological approach to visual perception. According to his theory, our perception of the environment inevitably leads to some course of action. We do not passively receive the sensory information from the world, instead, we actively search for information which allows to act. He also defined the word "affordance" as the possibilities for action. For example, a chair for sitting down, a button for clicking, etc. Nowadays, the theory of affordance has contributed a lot for design and the research of design related area.

### **2.2.1 "IN HAND" AND "PUT DOWN" MODE OF INTERACTION**

Lenay et al. (2007) proposed a scheme of sensory-motor coupling which illustrates the interaction between human and world, based on perception (Gibson, 1966) and phenomenology theory (Merleau-Ponty, 1945). According to them, perception is based on a law defining the sensory feedback for a full range of performed action (Figure 4). The perceptual system is a "coupling device" that modifies the lived body by defining the repertoires of actions and sensations available to the subject. Through the environment, the actions give rise to a sensory feedback that will provoke another action, and the action-sensation loop continues as the perception manifests itself. Perception depends not only on the sensory input, but also on the lived body's capacity for action. To give birth to a perception, a prosthetic device must be a coupling instrument that modifies the lived body by defining new repertoires of action and sensation. In this case, the perception is the result of a dynamic coupling between the subject and the object. For example, we use the mouse to manipulate the computer screen, and we look at the screen by moving and clicking the mouse with our fingers. Right now, we focus on the screen, but we do not look at the mouse anymore, because the object disappears into our consciousness. It has become a part of our hands.

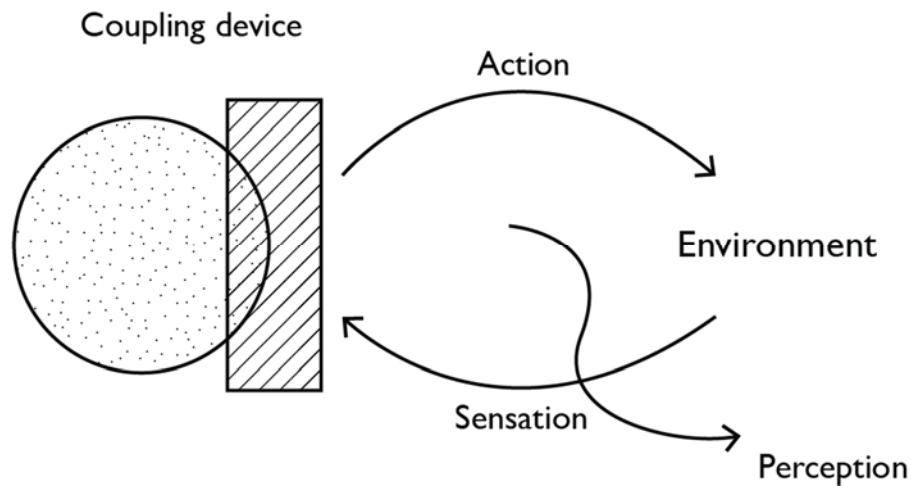


Figure 4. Sensory-motor coupling schema (Lenay et al., 2007)

According to the Lenay et al., the object can be alternatively perceived in the environment or as a coupling device between a subject and the world, thus modifying his /her perception of the world. These two kinds of perception give rise to the modes of existence of an object: the "put down" mode, where the tool is perceived in the environment, and the "in hand" mode where the tool is considered as an organ, which gives extension to the possibilities of action. An object in the "in hand" mode is used and grasped by a person to extend his or her capabilities to act and feel. For example, we wear our glasses, and we see the world through these glasses. However, we cannot perceive our glasses at this moment, which disappear from our consciousness. In that context, the object is a tool that we use to perceive the world. On the contrary, an object in the "put down" mode does not transform our perception, it can be modified, exchanged, etc. In the previous example, when we put down the glasses to clean and repair them, we can perceive them in the environment. These two modes alternate with each other in the utilization of the object (Figure 5).

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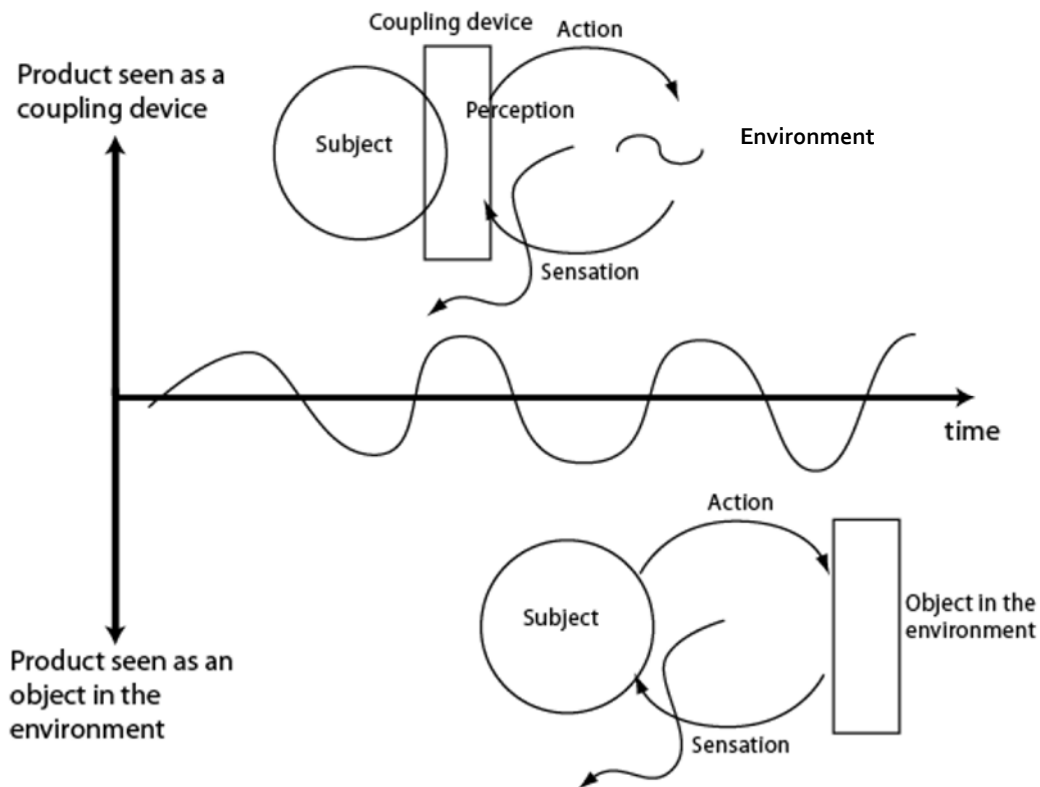


Figure 5. Sensory-motor coupling schema and two modes of an object (upper: in hand mode; lower: put down mode). (C. Lenay et al, 2007)

These two modes of existence of object give us fundamental notions for understanding the use of perceptual interfaces. They highlight that the interactive tool is not only an object that we can interact with, but a part of our coupling that we can interact through to perceive the task. They also match with two possibilities of design approaches: user interface design and user experience design which we are investigating in the following sections.

## 2.2.2 SENSORY SUBSTITUTION AND PERCEPTUAL SUPPLEMENTATION

A "sensory substitution" system can be thought of as a sensory prosthetic which transforms information of one perceptual modality (i.e. vision) into another alternative perceptual modality (i.e. touch). It is usually used to aid people with impaired perceptual modality to access the information with their unimpaired perceptual modalities.

A very famous device developed by Bach y Rita and his colleagues in 1969 – Tactile Visual Substitution System (TVSS) makes it possible for blind people to recognize simple targets by converting the images into a "tactile image". However, although this device made a commercial success, it is not widely used among the blind community (Lenay, Gapenne, Hanneton, Marque, & Genouëlle, 2003). Lenay et al. (2003) discussed the limits of sensory substitution. By just providing as much the information as possible constituting an object for discrimination and categorization, the TVSS device is not allowed to establish a common history between the person and external world in the course of interaction (people perceive the world through action). It lacks emotional values attached to an object, which

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ware called *qualia* (Bach-y-Rita, 1997). For example, if a blind person who cannot see from birth is shown an image of his wife, with the TVSS system, he cannot feel any emotion (Lenay et al., 2007). Therefore, instead of introducing new perceptual modalities, it is better to compensate for this deficiency by opening up a new space of human-world coupling: the perceptual supplementation.

Perceptual supplementation happens when a tool is grasped in the “in hand” mode. It transforms our capacities to act and to feel, and this tool becomes a part of our body. Therefore, when the perceptual interface is in the “in hand” mode, we constitute a lived experience through the interaction with the world, and emotional values accompany this lived experience. This means that each type of interaction leads to different perception thus to a different emotion. Therefore, the interaction can be designed to elicit lived experience.

The research on perceptual supplementation is fundamental for the design of perceptual interface with interactions. It emphasizes that our perception does not only depend on the sensory information, but as much on the person’s capacity for action (Lenay et al., 2007).

## 2.3 MEMORY

We all have had the experience that there is something in the world that we saw just for one second, and that we could remember, and there are other things we need to see several times otherwise we will forget it soon. This is a question of memory in our cognitive processing. There are two main perspectives in the role of memory in cognition: (1) traditional model of memory that highlight memory as a process of encoding, storing and retrieving, which exist inside the human brain and independent from sensorimotor mechanism (Wilson & Foglia, 2017), and (2) embodied experiences that are the basis of memory formation. Memory is not limited to an internal state of human, but it evolves, and changes based on the sensorimotor coupling with the artefact in the external world. The traditional model helps us understand the internal process of memory, while embodied perspective motivates novel insights about the external memory. We are going to discuss these two perspectives separately.

### 2.3.1 TRADITIONAL MODEL OF MEMORY

The traditional view of memory comes primarily from cognitivism, where memory is regarded as a process of encoding, storing, and retrieving information by human brain. According to the different ways of encoding, storing and retrieving, we have a sensory memory (SM), a short-term memory (STM), a working memory, and a long-term memory (LTM). The most popular memory model in this perspective is the Atkinson & Shiffrin's (1968) memory model. In their model, they talked about three types of memory: sensory memory, short-term memory (STM) and long-term memory (LTM). The STM and the working memory are often used interchangeably, however, they are slightly different. It is considered that working memory contains the STM and other information-processing systems (Baddeley & Hitch, 1974; Cowan, 2009).

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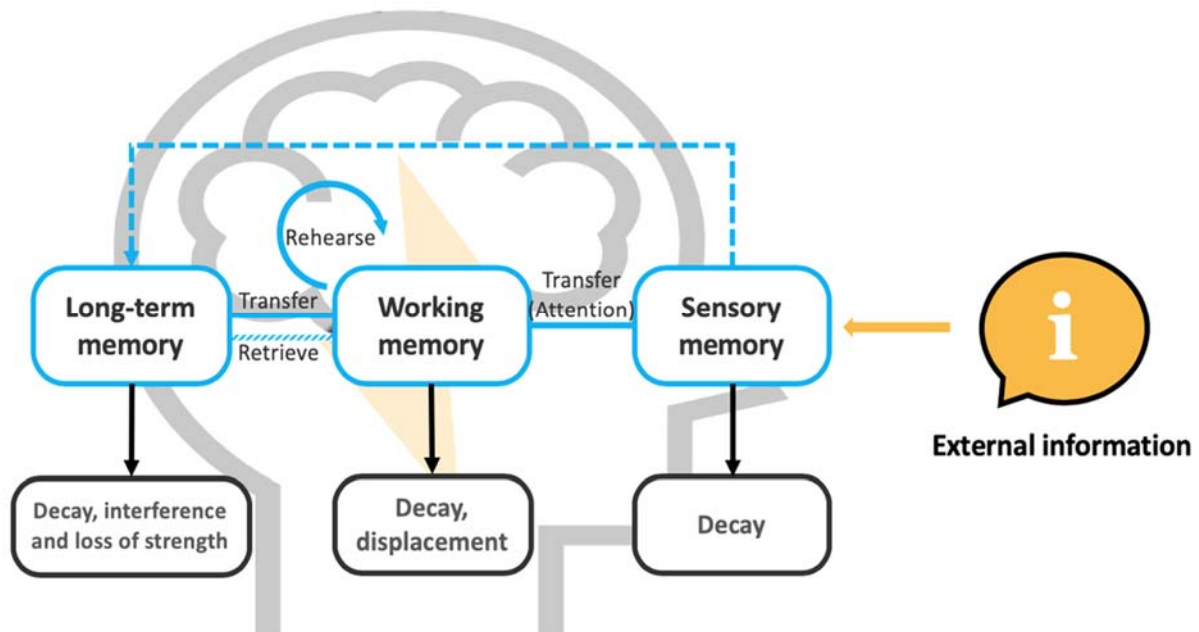


Figure 6. Illustration of Multi-store model of memory (Atkinson & Shiffrin, 1968), working memory replaced STM.

Briefly, the sensory memory registers input from the external environment, and we pay attention for it to transfer it to the working memory. Finally, we rehearse it elaborately to store it in the LTM. Of course, the working memory can also directly retrieve information from LTM. Some information can bypass the STM (visual in particular) and go directly to the LTM.

### 2.3.1.1 The sensory memory

The information that people gained through sensorimotor loop does not disappear immediately after the stimulus stops functioning. For example, when we see a person in the street, and we look at the person walking on the road just for one second, we can remember some details of the appearance of this person, such as the color of the clothes, the height and so on. That is because our sensory memory stored this sensory information so that we can remember it. A famous study of the sensory memory is the Sperling's experiment for visual memory in 1960. Participants were shown an array of letters for recalling all of them or a specified row within a short time. The participants reported that they had seen more than they could remember. The results showed that our sensory buffer stores more information than that we can recall. It is stored in our sensory memory for just a very brief period of time (less than one second) before it is transferred to the working memory (Sperling, 1960). This information could be decayed quickly in our sensory memory and can be overwritten by further information from the same sensory modality (Neisser, 1967). Therefore, the sensory memory is considered as a temporary buffer where information can be accessed shortly in different modalities and after that, the information can be lost due to the decay or an interference from a new stimuli (Atkinson & Shiffrin, 1968).

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The sensory memory does not participate in higher cognitive functions (information comparison and memory consolidation), it just captures a snapshot of everything that we sense (Dick, 1974). However, our attention can control and decide, which information can be transferred to the short-term memory to be processed ( Craik & Lockhart, 1972). The sensory memory is the first stage of information storing in the information processing.

### 2.3.1.2 The working memory

The working memory is the second stage of memory and is considered as a buffer, which stores information relevant to the current task. The STM and the working memory are often used interchangeably, however they are quite different and related. The STM was first proposed by George A. Miller. He thought that before the information enters the long-term memory, we need a temporary space to store the received information. Then he proposed the theoretical concept of "short-term memory". Miller (1956) found that the STM can store information, usually  $7 \pm 2$  chunks of information, for a short amount of time. A chunk is an information block that unite information through meaning. For example, for people who are familiar with SAP, they know that that "SAP" stands for a software company, therefore "SAP" is one chunk. But for others, it may be three chunks (the three letters). Miller's magic 7 reflects the limitation of the STM.

In their article about the "working memory" Baddeley & Hitch (1974) examine its role in reasoning, comprehension and learning. It has been widely used not only in cognitive psychology but also in other areas, and it is considered that the working memory contains the STM and other information-processing systems.

In 1974, Baddeley and Hitch proposed a working memory model based on the experiment of short-term memory impairment (Baddeley & Hitch, 1974). They conducted a series of experiments to examine the role of the working memory in reasoning, language comprehension and learning. The participants were asked to remember 1 to 6 letters while performing another task. They had to judge the order of two letters presented in the sentences (the order was shown in advance). The results showed that the additional STM loads more than two items, which can impact the task performance. The experiments suggested that the working memory represents a control system with limits on both its storage and processing capabilities.

Similarly, Cowan (2009) also discussed the difference between the STM, the working memory and the LTM. In his definition, the working memory includes the STM and other processing mechanisms that help make use of the STM. However, he thought that the difference between the STM and the working memory just depends on how people define them. Nowadays, the working memory is a concept that has been increasingly used in the scientific research.

The information in the working memory is always active as needed for current work. Therefore, the working memory plays an important role in information processing. It makes us aware of our current psychological activities, helps us construct an entire memory image through processing information in the sensory memory and allows us to make sense of the

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world. Although the working memory is limited in capacity, it always saves the latest information-processing results until the final goal is achieved.

### 2.3.1.3 The long-term memory

The third stage of information storage is the long-term memory (LTM). After the information in the working memory has been identified, processed and assembled, it is transformed into permanent information stored in the LTM. Unlike the sensory and working memory, the LTM has theoretically an infinite capacity, and information can be stored there for a life time.

The information in the LTM can be referred when we are performing a task. The LTM can be divided into two categories: explicit and implicit memory:

- the explicit memory, also called declarative memory, is about descriptive knowledge, which requires conscious thought. For example, the knowledge learned during the class or recalling what you did for vacation last year. The explicit memory tells us what it is,
- the implicit memory is about assembling knowledge, which does not arise from conscious thought. For example, how to ride a bike, swimming, etc. The implicit memory tells us how to do it.

Most of the information stored in the long-term memory is “in hibernation” and it is hard for people to realize it. It can only be activated and extracted in chunks in the working memory, when the sensory organs are stimulated by the outside world and need to use their own knowledge and experience to acquire a new sensory experience. It is worth mentioning that information can also decay due to interference or the lack of extraction. Therefore, an effective way to maintain the LTM is continuous information extraction and repetition (Atkinson & Shiffrin, 1968; Card et al., 1983).

The sensory memory receives information from the environment through visual, auditory and other sensory channels. The information is kept in the sensory memory for a short period of time, some of which are selected by attention and processed by the working memory. Then, some of this selected information in the working memory is transferred to the LTM, but usually the information in the working memory has been associated with some other information of the LTM before entering into the LTM. So there is a bidirectional flow of information between the working memory and the LTM. They are different in retention time, storage capacity and forgetting mechanism (Atkinson & Shiffrin, 1968; Card et al., 1983; Cowan, 2009; Craik & Lockhart, 1972).

The traditional model of memory claims that information storage and retrieval are independent from the sensorimotor mechanisms. However, this point of view ignores the role of the sensorimotor loop in the formation of memory. We interact with the world at every moment, which helps us recall our knowledge and make sense of the world. We propose to complete this model with the embodied memory. The embodied perspective has motivated novel insights about memory, which highlights the importance of the



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relation between the external environment and the human memory. The external information presented in front of people is also a type of memory that helps people recognize and recall the internal memory and build the connections to make sense of the world.

### 2.3.2 THE EMBODIED MEMORY

When we remember a thing such as how the toolbar is displayed to edit the text in the Word software, we do not only remember the semantic relatedness of each tool, such as its name, its icon, but an image revealing where these tools are located in the toolbar and imagine actions to take throughout the toolbar. The location itself acts as an external aid to memory and the imagined embodied actions within the location afford the retrieval of information that help understand what is available to edit the text (Cole, Hood, & McDermott, 1997). It could be argued that the memory of how to edit the text is in fact stored in the environment, rather than in our mind. There are cues which remind us how to format, change the color, etc. as we see them, stored in our memory. The rest of the information is stored in the environment.

Studies have shown the role of the body in the articulation of memories. Memories can reflect different body capabilities. For example, when the speaker makes a speech, he usually talks accompanied with some gestures. The gestures serve as tool not only for communication but also to facilitate the maintenance of spatial representations in the working memory (K. Wesp, Hesse, Keutmann, & Wheaton, 2001). This indicates that motor information may be a part of the memory trace.

With this respect, the memory is not merely a storing and retrieving storehouse, it is rather embodied through lived patterns of the interaction between the human and environment (M.A., 2017). Through the enactive approach, we re-think the construct of memory and we are focusing on the embodied experience as the basis of memory formation. Therefore, we propose to complete the traditional model of memory previously shown in Figure 6 with the embodied memory in the Figure 7 below.

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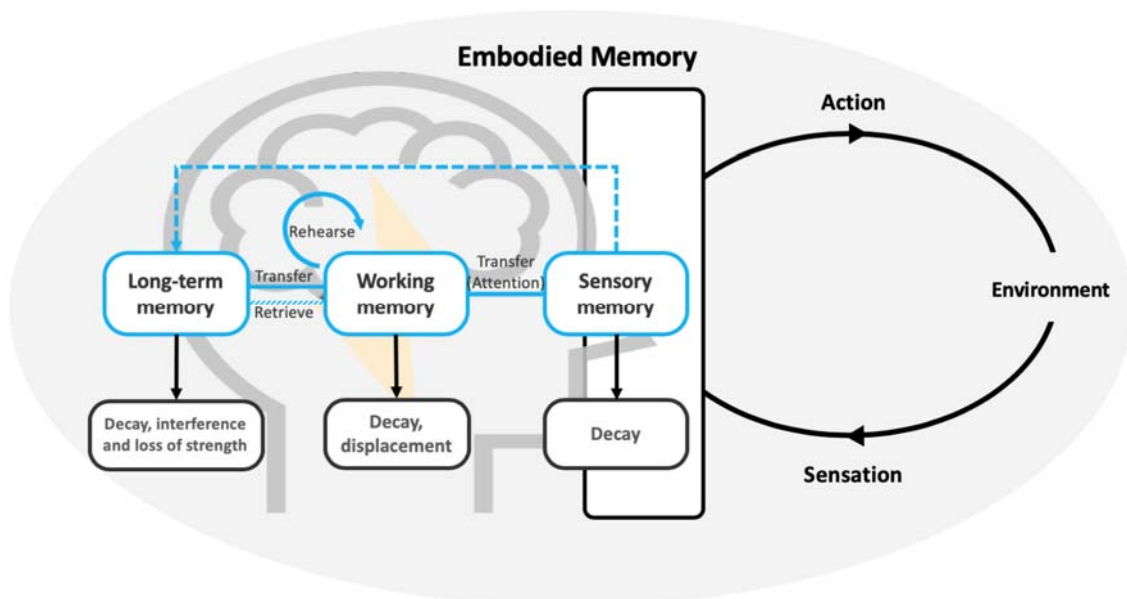


Figure 7. Complete the traditional model of memory by embodied memory

The embodied memory helps human construct a relation or a complete consciousness of an object or an event in the present moment (1) through the sensorimotor coupling between the human and the world; (2) through the sensory memory and the working memory to store the external information; and (3) through the recall of the long-term memory to retrieve the relevant information. In the context of a task resolution, the information we need to do the task is always active in the present moment. This means that it is stored in the working memory. The limitations of the working memory builds barriers for users to accomplish the task, such as low performance, negative emotional effects, etc. The embodied memory gives us a new perspective to design an appropriate user interface that serves as an external memory, enabling action-sensation loop to alleviate the memory load.

As mentioned in the introduction, task interruption is a common phenomenon in daily working environment, and it has negative effects on the resumption of task. We examined the related work studied in the task interruption and task recovering, which highlight the research problem and the necessity to address it from the embodied perspective.

## 2.4 TASK INTERRUPTION AND TASK RECOVERING

*You are working on a financial analysis report that is due next week, when a marketing campaign analysis report is coming to you that should be done tomorrow. You save the financial analysis report in the system and put it aside. You are now working on the new task. The next day, you return to the suspended task. Has it ever happened that you cannot remember all what you did last time and what you were going to do next? Will this interruption affect your task performance? If so, are there features or functions that can be designed into the system to reduce this interruption effects?*

Today's working environment and the rapid development of technology allow people to work on several projects and tasks at the same period of time. In addition, the popularity of

instant message, email, meetings challenges people to handle different kinds of notifications. All this increased the phenomenon of task interruption and suspension and requires users to resume these tasks later in their everyday human-computer interaction (Mark, Gonzalez, & Harris, 2005). Recent research works have demonstrated that the disruptive effects of interruption on complex decision-making tasks (E. M. Altmann & Trafton, 2004; Ratwani, Andrews, McCurry, Trafton, & Peterson, 2007; Speier, Vessey, & Valacich, 2003). This is followed by the research of task resumption, which has been one of the key concerns of HCI researchers.

In this section, we reviewed related work in task interruption and resumption, which give us implications for design and research.

### **2.4.1 UNDERSTANDING THE EFFECT OF TASK INTERRUPTION**

When a primary task is interrupted or suspended, its common effect is the delay and failure of task resumption. Czerwinski, Horvitz, & Wilhite's (2004) diary study of task interruptions showed that users have difficulty in reinstating suspended tasks, particularly complex problem-solving tasks, because they involve high cognitive load and require attention, which are vulnerable to interruptions. The effect of interruption has been studied on a user's task performance and emotional state in human-computer interaction (Bailey, Konstan, & Carlis, 2000). In their review of psychological literature on interruption S. Y. W. Li, Magrabi, & Coiera (2011) summarized three frameworks to understand interruption effects:

The memory for goals theory (E. Altmann & Trafton, 2002) suggests that our memory usually processes the goal with the highest activation level. When the primary task is interrupted, its activation level decays over time. According to this theory, to resume a suspended task, we should activate the suspended goal by retrieving it from memory or external cues.

The prospective memory (Dodhia & Dismukes, 2009) refers to the ability to remember things or tasks to be done at a certain moment in the future (e.g. go to cinema after work). Studies showed that people tend to forget what they were told to do when a secondary task is intervened, which leads to prospective memory failures (Edwards & Gronlund, 1998; Eldridge, Sellen, & Bekerian, 1992).

The multiple resources theory (Wickens, 2002) states that when two tasks compete for the same processing resource, their task performance will be hindered to a certain extent. This processing resource includes stages (perceptual/cognitive vs response), codes (visual vs spatial), sensory modalities (auditory vs visual) and visual channels (focal vs ambient). The most relevant to interruption are sensory modalities. Based on this hypothesis, when two tasks are allocated to different modalities (one visual, the other auditory), they can be executed concurrently. On the other hand, when one task consumes all the processing resources leaving no resources to another task, the other task has to be suspended, which is seen as an interruption.

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The memory-based theory explains the memory process of interruption occurrence. The multiple resources theory explains the task interference and multi-task performance from the cognitive resource allocation's perspective. Since our working memory is limited in capacity and decays over time, once we are interrupted by a secondary task, we have to free up some space of our working memory to hold more information for the secondary task. However, the removed information from our working memory will be still needed to resume the interrupted task. Therefore, we may often end up working harder and spending longer to finish the task. These three frameworks are useful for explaining the effect of task interruption underlying primary task resumption and user experience design for easing our working memory overload.

## 2.4.2 TASK RESUMPTION

Since the interruption has distracted users from ongoing tasks and caused problems for returning to suspended tasks, the study in task resumption and reconstruction has been paid much attention both in cognitive psychology and HCI domains.

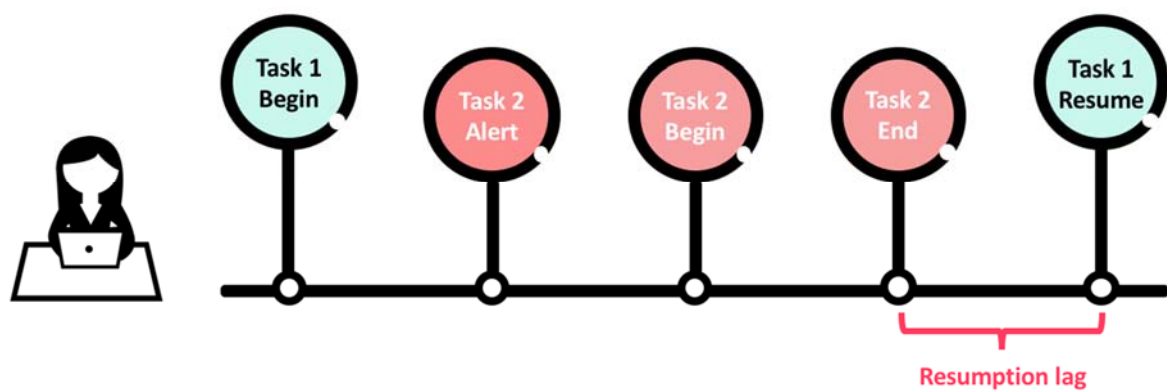


Figure 8. Illustration of task interruption and resumption process (Modified from E. M. Altmann & Trafton, 2004)

The negative effects of complex task interruption led to research grounded in cognitive psychology aiming at task resumption as a memory-based process (E. M. Altmann & Trafton, 2004; Gartenberg, Breslow, McCurry, & Trafton, 2013; Monk & Kidd, 2008; Parnin & DeLine, 2010; Ratwani et al., 2007; Trafton, Altmann, & Brock, 2005). For example, to measure the disruptive effect of task interruption, E. M. Altmann & Trafton (2004) proposed a behavioral measure called *resumption lag* to examine the disruptive effect of task interruption and its relation with the external cues (cursor, red arrow pointing to participant's last action, etc.) associated with the interrupted task. The resumption lag is "the time needed to 'collect one's thoughts' and restart a task after an interruption is over" according to E. M. Altmann & Trafton (2004) (See Figure 8). They found that the availability of some cue before an interruption can reduce the resumption lag, which facilitate the task performance. Trafton, Altmann, & Brock (2005) also examined the effect of environmental

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cues in supporting task resumption, which can help users to resume a suspended task faster than without cues. Apart from memory for specific suspended goal, the memory for spatial location to task resumption has been also studied. Ratwani et al. (2007) showed that maintaining a spatial representation of the primary task facilitates task resumption. The information systems supporting a visual feedback (e.g. progress bar) on task suspension can help people be aware of the task and its status and motivate an immediate resumption of the suspended task (Liu, Jia, Pan, & Pfaff, 2014). Leiva, Matthias, Gehring, & Kr (2012) proposed design implications for designing mobile interaction to reduce the overhead caused by application interruptions, such as preparation for being interrupted and providing guides for going back into tasks (replying last N milliseconds of UI interactions, giving a hint of what was done or a visual on-screen cue for example).

These works are based on the memory process, which focuses on reducing the resumption lag for a better task resumption. However, it is more suitable for dealing with the immediate interruption and resumption of tasks, and cannot easily translate to the applied domains considered in our work (Salvucci, 2010). As stated, there is a great difference in the resumption lag between the applied HCI literature (several seconds or more) and memory-based account (ten to hundreds of milliseconds to at most one second). The context of interrupted task is more complex in real-world problem-solving tasks than that in a simple experiment on remembering only one or two items. For example, an analytical task involves rich mental context about the steps of analysis, one's strategy and intentions, which also need to be restored.

### 2.4.3 RESTORING MENTAL CONTEXT

Salvucci (2010) proposed a theoretical framework for reconstruction of task context after interruption. This framework provides a way for representing the reasoning task context (problem state) and specifying the reconstruction process (action, perception and cognition). It is illustrated by two sample task domains – a route-planning task and a document-editing task, which makes it limited and particularly is not easy to generalize the reconstruction process. However, it gives us a new way of rethinking the task resumption, not only to recover a suspended goal (reduce resumption lag) but also restore their task context and mental context.

The observational study made by Jones, Bruce, & Dumais (2001) showed a diversity of methods that people use to manage web information for future use. For instance, people emailed useful web links (URL) to themselves or others; other methods include saving web pages to hard drive, pasting the web links to a document. The main reason for these methods is to keep reminding as people check their mail regularly. On the contrary, the bookmark and history list functions do not have this "reminding" function, which are less used by users.

Parnin and his colleagues surveyed developers on the nature of their current strategies for task resumption. They found that developers usually take notes before task suspension and search for other sources of task context (cue seeking) during task resumption. They

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discussed the necessity of memory aids that development tools should provide (Parnin & DeLine, 2010; Parnin & Rugaber, 2011, 2012).

M. G. Lamming & Newman (1992) conducted an experiment in which participants were asked to remember what they did on a particular day without and with a video diary. The study showed that the video diary helped to enhance the memory recall. Lamming et al. (1994) defined the applications with human memory support as a *memory prosthesis* when memory problems happen. It is useful for remembering by recording automatically data about users' past activities.

According to the study of Czerwinski & Horvitz (2002), the participants were asked to recall computing tasks after 24 hours and one month with a video-based prototype. The video-based prototype was a one-hour segment of desktop computing tasks that participants realized. The result showed that the users' memories about important events and events orders can be augmented significantly with the help of video reminder prototypes.

Some memory aid tools are also developed to study the context recovery, like Morris, Morris, & Venolia (2008) who introduced a *SearchBar* tool for organizing a web history that assists the search context resumption and information re-finding. They evaluated its usefulness for users to complete a complex search task. Waldner, Bruckner, & Viola (2014) presented a node-link representation of visual history across applications to assist recall of past operations and recovery details of information foraging tasks.

Ragan & Goodall (2014) proposed a method for evaluating the level of details in visual history in data analysis task. It proved that visual history helps process recall and even with reduced data-resolution, was effective for aiding process memory recall. The visual cues alone from the final workspace were enough to improve memory of the main themes of analysis.

Rule, Tabard, & Hollan (2017) made two studies on how users reconstruct their mental context for resuming suspended tasks. In the first study, they discovered that the use of thumbnail images to reconstruct detailed mental context of earlier computer work is very common among users. In a second observation study with web developers, scientific writers and graphic designers, they found that they are getting used to narrating the cues in their documents with implicit meanings to reconstruct their mental context. Their work provided a proof of the usefulness of visual histories in reconstructing mental context.

Prior works on the task interruption and its negative effect that caused human memory problems from cognitive psychology and HCI's perspective were conducted for knowledge workers in different working situations (computing events, programming, route-planning, writing and web searching). These studies suggested that it is necessary to design memory aid tools for recovering users' mental context and task context from their interrupted and suspended tasks. They also gave us some design implications for memory aid:

- cue selection – what part of the past activities (images or videos) to select for minimizing the cues size?

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- visual representation – how to effectively represent these cues through timeline, network diagrams?
- enabled interaction – what kind of interaction can be available to enhance the review of visual history and task resumption?

## 2.5 CHAPTER SUMMARY

This chapter allowed us to position this research work in the theoretical framework adopted from multi-disciplinary points of view.

We have positioned our research on the enactive approach and sensorimotor perception, highlighting the action and sensation loop in the interaction between human and environment. This has been ignored by cognitivism that considers human mind as a computer. From this perspective, we also examined the traditional model of memory that does not consider that memory can also be constructed from the sensorimotor mechanism. Based on these two observations, we reviewed some of the works, which have been done in the context of task interruption and task recovery. They put into light some of the key elements, which lower the efficiency of task resolution achievement when they are interrupted, and which could improve task recovery, all of which are linked to human memory limitations. We then focused on the design of memory tools that can make up for these limitations. In the next chapter, we then present a review of some of the instrumentation approaches, which have been developed for task recovering aid.

## CHAPTER 3 INSTRUMENTAL FRAMEWORK

*"Reflective reasoning requires the ability to store temporary results, to make influences from stored knowledge, and to follow chains of reasoning backward and forward, sometimes backtracking when a promising line of thought proves to be unfruitful. ... the process is slow and laborious"*

— Donald A. Norman, American scientist

*"Design is not just what it looks like and feels like. Design is how it works."*

— Steve Jobs, American co-founder of Apple, Inc.

In this chapter, we review the tools that have been realized to solve the problem of task recovering in the context of analytics. Based on the limitation of the traditional model of memory which does not take interaction into account, we proposed the memory support tool which serves as a supplementation of our perceptual system. In order to instrument our proposition, we also reviewed the design principles in HCI and UX domains. This will help to build the tool and conduct the following experiment.



## 3.1 THE PROBLEM OF ANALYTIC PROVENANCE

The task interruption is a general phenomenon in today's work environment. The previous section gave a review of the related work that has been done in a broad domain and implies some insights for designing history tool for recalling and reinstate the context of the interrupted or suspended work. In the world of analytics, this is also an inevitable problem for business users and data analysts.

When doing an exploratory visual data analysis, business users regularly iterate the visual analysis steps to investigate, review, test hypothesis, and summarize the questions and findings. In addition, when a project requires multiple analysis sessions, which last for long periods of time, the task can be interrupted or suspended. Users try to find from "how did I get here?" to "where have I been" to reinstate their reasoning process. As our working memory is limited in its capacity and decay (Cowan, 2009), remembering and tracking the history becomes a barrier for exploration and commitment. Therefore, it is beneficial to design tools that help people to recall their interaction history, and to live a positive user experience.

### 3.1.1 ANALYTIC PROVENANCE

Shneiderman (1996) noted that tools enabling the display of users' interaction history supporting iterative analysis allow users to review, retrieve and revisit visualization states during the information visualization process. Since then, there has been more research on interaction history in analytics, HCI and other fields.

Heer et al. (2008) summarized a range of design decisions in designing interaction history systems. They include the organization of history analysis using states and actions, its visual representation such as linear or branching layout; the operations it supports such as navigation, editing, search, filter and export.

The first workshop on analytic provenance was held in 2011. *Analytic provenance* has been introduced to discuss its utilization in assisting users in solving real world problems (North et al., 2011). It focuses on the history of the analytic process for understanding the reasoning process through visualization interactions. In this workshop, they proposed five interrelated stages in the research of analytics provenance: perceive, capture, encode, recover and reuse:

1. perceive: user's interaction with the visualization can only happen after perceiving the data visualization,
2. capture: what kind of interactions should be captured, the command "undo" and "redo" are available in most applications (Heer et al., 2008),
3. encode<sup>3</sup>: how should the system store the captured user interactions?

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<sup>3</sup> Encoding refers to the process of describing the captured provenance in predefined formats.

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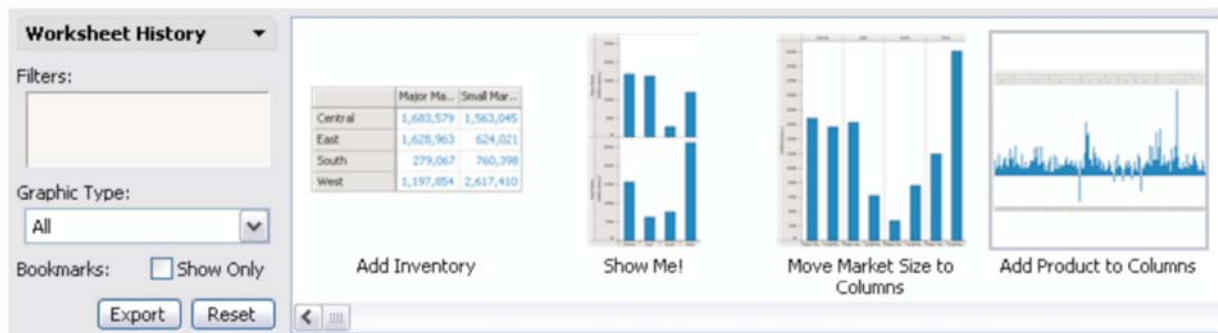
4. recover: how can user's mental context be recovered, making user understand their sense-making process?
5. reuse: how can the system apply what it has learned from the user's reasoning process to help the user for future analysis? or Can the user's reasoning process be applied to other tasks or systems?

In general, the history tools that can capture and represent analysis information, mostly propose the five elements presented above.

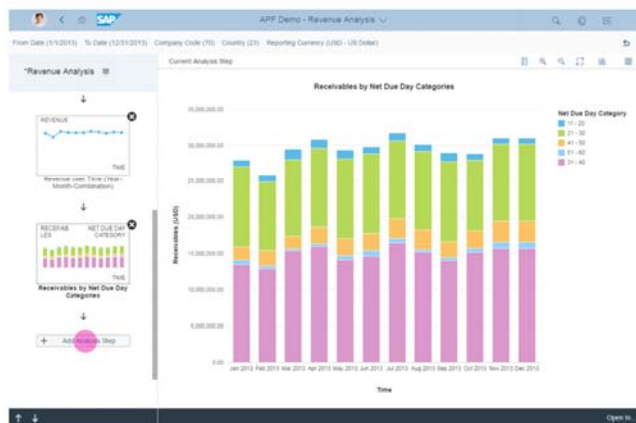
### 3.1.2 HISTORY TOOLS

Many visualization tools have been realized to help people recall their memory through analytic provenance, we list some of them based on different representations: linear and node-link visualization for example:

1. Linear representation



Tableau



SAP APP



Analytic trails

Figure 9. Provenance tools with linear representation

*Tableau* (Tableau Software Inc.) has integrated with a history bar which can record and visualize interaction histories, support data analysis and communication of findings, and contribute novel mechanisms for presenting, managing, and exporting histories (Heer et al., 2008). *Tableau* is an example of linear representation of thumbnails of analysis visualization. But there is no explicit link between the thumbnails, which may lead to difficult interpretation after interruption.

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*The SAP Analysis Path Framework (APF)* is a framework for creating interactive chart-oriented analytic drilldown apps. It enables business users to interactively create and save their own analysis path by combining different analysis steps and applying filters. It provides business users and managers with an intuitive, easy to use analytical tool to perform interactive data explorations and drill-down analysis for root cause investigations. However, users have to create their own analysis steps manually.

*Analytic Trails* of Smart Decision (Lu, Wen, Pan, & Lai, 2011) is a web-based visual analytic tool, with the goal of which is to help business users to derive insights from structured and unstructured data. Smarter Decision automatically captures the trail of the user actions taken during visual data exploration. Trails can be bookmarked and restored to replay the actions and can be shared, modified and applied for a new analysis thus facilitating the reuse and/or sharing of the established method for analyzing a given data set.

These analytic tools provide history functions through analytic provenance, which allow users to review their history analysis steps after interruption. However, the visual analytics process is often complex containing back and forth reviewing. Thus, the linear representation makes it hard to explain the analysis logic, and then causes difficulties for users to reinstate their mental context for interrupted or suspended tasks.

## 2. Node-link representation

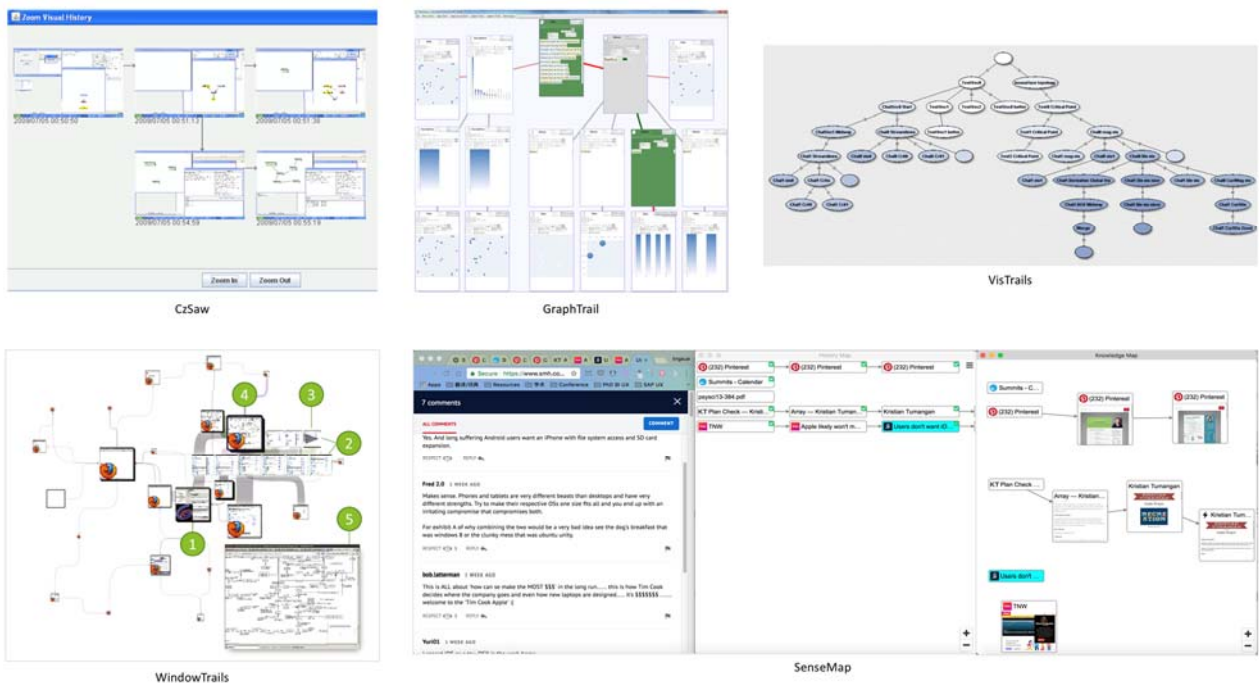


Figure 10. Provenance tools with node-link representation

*Czsaw* (Kadivar et al., 2009) is a visual analytic application for investigative analysis problems where the data consists of collections of documents containing identified entities of various types. It consists of a data viewer, which displays lists of

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documents and entities, a script of statements generated by user interactions, a dependency graph of script generated data elements and a history view of all prior stages of a given analysis. Its history view is represented by a node-link graph showing data views that were open at different times throughout an analysis.

*Graphic Trail* (Dunne, Henry Riche, Lee, Metoyer, & Robertson, 2012) uses the spatial organization of one's analysis to explain the past exploration. This tool supports some interactions such as the visual feedback reacting to mouse event, for zooming to see more details. However, the user has to create his/her own path by organizing the charts, and it is not scalable when there are large number of charts for management.

*VisTrails* (Bavoil et al., 2005; Callahan et al., 2006) is a scientific workflow and provenance management system that provides support for data exploration and visualization<sup>4</sup>. It automatically keeps track of the provenance of the discovery process, by maintaining a detailed history information about the steps followed and data derived in the course of an exploratory task. A vistrail consists of an analysis pipeline as a node-link graph where each node corresponds to a user's command and an edge represents a set of change actions between the nodes.

*WindowTrails* (Waldner et al., 2014) is a cross-applications desktop history tool that helps users recall their past operations and rediscover the previous information resources. The history view consists of used desktop resources with nested snapshots and video sequences through node-link diagram.

*SenseMap* (Nguyen et al., 2016) is a browser-based extension to support sense making through analytic provenance. It automatically captures users' browsing pages links and represented in multi-linked views using icons and textual descriptions. It also enables users to curate and communicate their finding in knowledge map, which improves their understanding of the tasks. However, it needs users to switch between the different views in the browser to review their history map and actively organize the information by adding the relevant history into the knowledge map.

Data analysis and visualization are iterative processes. The linear representation of one's provenance of past activities shows what people did last time, but it lacks an explicit relation between each activity, which causes a barrier between user exploration and explanation. The node-link graph represents the interaction history structure and the relations between the histories, which is more understandable. However, its effect is also limited to the volume of information: the more information it has, the less meaningful it is. We should be aware of that when using the node-link diagram.

In addition, these tools are usually called out in a separate interface. They are supported by a set of operations on the history such as navigation, editing, sharing, etc. However, there

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<sup>4</sup> <https://www.vistrails.org/index.php/>

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are rarely studies on how to engage the user in the interaction to go back to the analytic province instead of statically representing it in the interface. The latter one is relatively passive and is designed where the analytic provenance is an objected perceived directly in the environment. The coupling of user action and provenance function is indirect in terms of the time and space consistency. The provenance function can provide the information of “what have I done?” but doesn’t make them aware of “what hasn’t been done?” and “what should I do next?” using our perceptual system. There is a scarcity on the design of the provenance tool in a natural coupling with current user action, which could provide users an experience for returning to the analytic task through their provenance. In the next section, we present the theoretical work in human-computer interaction and user experience design which structures our research work in the design perspective.

## **3.2 HUMAND-COMPUTER INTERACTION - MEMORY SUPPORT**

In the design of interactive information system, users’ working memory could be overloaded in their working memory depending on the task complexity and the user interface. This load is mainly the mental effort that users consume for acquiring, understanding and making decision during the interaction with the system. The working memory acts as an intermediate converter for sensory memory and the LTM. The source of information in the working memory comes either from the sensory memory or past experience, knowledge or skills from the LTM. However, it is limited in capacity and processing capabilities. When the task is hard and requires much information to be kept for processing, we need to release information previously stored and process the new information in our working memory. However, the released information is still needed to complete the task, and we may spend more time to recover the information or we could make mistakes. The working memory’s capacity varies from people with different education, expertise, etc. For example, a novice developer could have less working memory than an expert, for who the program task is so easy that it does not burden his/her working memory, while the novice may spend more time completing it because he did not have this experience before. The novice needs more working memory space to process the new knowledge. The job of a designer is to design a good user experience for every user, therefore a general good practice of design to reduce the mental load that puts on users’ working memory is quite beneficial (Budiu, 2018). It is about to make the information needed for the task accessible for users through user interface and interaction – an external memory for supporting our working memory that we will address in the following section.

### **3.2.1 MEMORY SUPPORT IN SENSORY-MOTOR COUPLING**

We address the memory problem from the perspective of Charles Lenay's sensory-motor coupling as we explained in the previous section. We will consider here the tool for memory support to reduce users’ mental load in task resolution in two modes: the “put down” where the tool is perceived in the environment, and the “in hand” where the tool is considered as an organ, which gives extension to the possibilities of action. As such, if there exists a

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memory support in information system, it can be alternatively perceived in the working environment and as a coupling device between the user and the task, thus modifying one's perception of the task. When the memory tool is in the "put down" mode, it can indicate the history of the past actions allowing the re-visitation of the task, which can be perceived and acted on as a *memory substitution*. When the memory tool is in the "in hand" mode, it acts as a coupling device which extends the user's capability of perceiving the task as a supplementation of his/her perceptual system. In this case, we consider it as a *memory supplementation*, which derives the exploratory actions corresponding to the user's actions, thus providing a lived experience. The user can adjust his or her behavior based on his/her perception of the system's feedback and the context of use; once the context of use is changed, the user adapts to this change and adjusts his/her behavior accordingly.

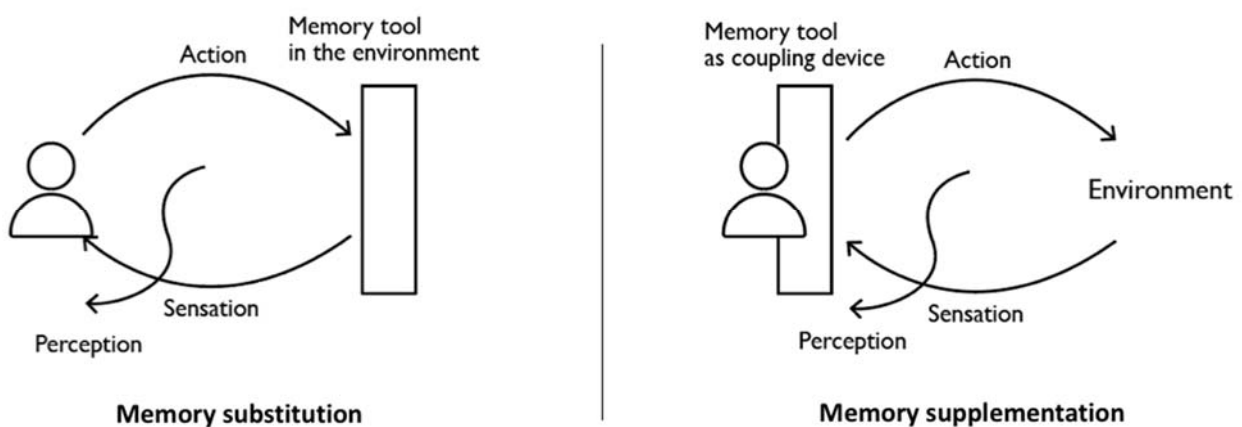


Figure 11. Memory substitution vs memory supplementation based on sensory-motor coupling

Therefore, a memory substitution is a memory support, which reminds the user what has been done in the past, while a memory supplementation may make the user aware of what has not been done, and what to do next. During this process, the action plays a decisive role in the perception. This sensory-motor coupling gives us a new perspective to think about the design of user interface: the memory substitution corresponds in the first place to information entering into the user's five senses (mostly visually), and the memory supplementation happens depending on user's consecutive actions on the user interface. The action plays a decisive role in this process. Therefore, the user interface should be designed as a coupling to the user's action, which invites the user to actively involve and engage in the interaction with the task. It is a question of how to create the opportunity for an action that can be perceived by the user. We need to study the related design principles in the context of interaction design that will help us explore opportunities for the design of memory supplementation support.

### 3.2.2 NORMAN'S GULFS OF EXECUTION AND EVALUATION

One of the main issues existing in human-computer interaction, according to Norman, is the *Gulf of Execution and Evaluation*. It describes the two main challenges that must be overcome by users to successfully interact with any device. It is the role of the designers to

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bridge these two gulfs by providing the right information in the system. From the *Figure 12* below, we can see that users are trapped in an (almost) endless loop, alternating these two issues: After the execution of the given step of a task, they must evaluate the results, plan to perform the next step, then evaluate the results, and so on, until they reach the desired goal and exit.

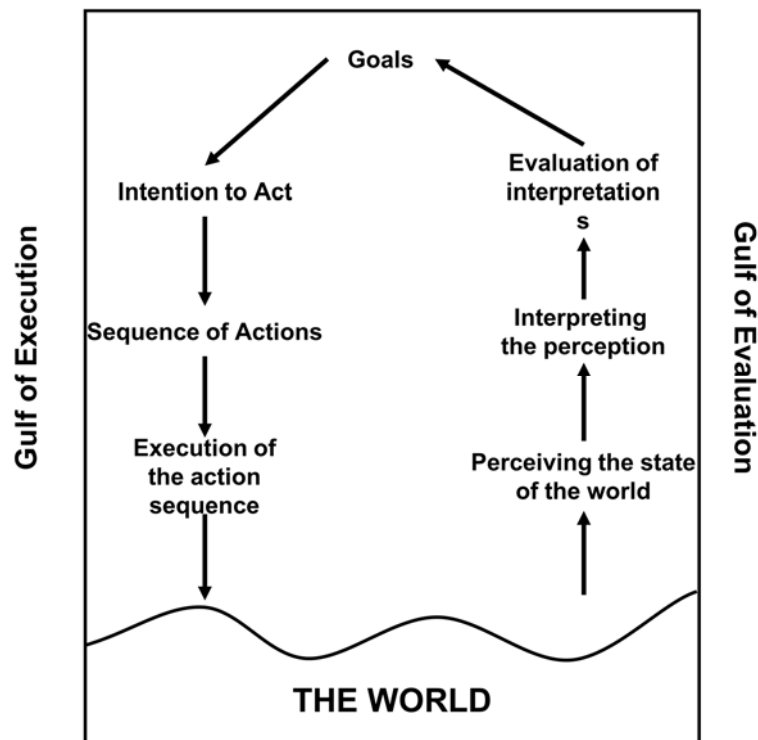


Figure 12. The Gulfs of Execution and Evaluation yielded from the Seven Stages of the Action (adapted from D. A. Norman, 2013)

The gulf of execution is the gap between the user's intention and the allowable operations. One of the ways to measure this operation is to see if the system provides an operation that matches to the user's intention and allows the user to do what he/she wants to do easily. The gulf of evaluation reflects how much efforts must be made to interpret the physical state of the device and to decide whether or not the expectations and the intentions have been met. If the user can easily obtain and easily interpret the information provided by the system about the operational status, and this information is consistent with the user's view of the system, then the gulf in the evaluation is very small.

How to bridge the two gulfs? We need to delve into the psychology of human actions (D. A. Norman, 2013). These two gulfs involve two parts of an action: execution and action (doing) and evaluation of the results (interpreting). Users are doing something for achieving a goal, it is the trigger of an action. The goal is followed by a series of actions in the execution and evaluation phase. They are *Goal*, *Plan* (the action), *Specify* (an action sequence), *Perform* (the action sequence), *Perceive* (the state of the world), *Interpret* (the perception) and *compare* (the outcome with the goal).

For instance, a user signs up for a news website.

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1. Goal: the goal determines the context of design.
2. Plan: open the web browser and website and find the sign-up information.
3. Specify: decide a sequence of actions usually subconsciously, such as open the webpage, click on the sign-up button, fill in the form and submit.
4. Perform: execute these actions.
5. Perceive: perceive every consequence after each action, i.e. if it has the correct feedback.
6. Interpret: explain the perception thus have cognition or emotion.
7. Compare: compare if the outcome is consistent with the goal and evaluate.

Before the discussion of the design solution, it is necessary to grasp the user's seven stages of action, and to understand design issues to be solved behind each action through the decomposition of the actions. The seven stages of action are useful for understanding human behavior and for guiding design especially in designing interaction. Based on this model, several design principles to bridge the gulfs of execution and evaluation are studied, we present two of them in the next sections: affordances, feedforward and feedback.

### 3.2.3 AFFORDANCE

The concept of affordance was originally coined by the American psychologist James J. Gibson (Gibson, 1986) to imply the complementarity of the environment and the animal. He believes that we perceive the environment directly without an excessive amount of internal processing such as learning. He defined this concept as follows:

"The affordances of the environment are what it offers the animal, what it provides or furnishes, either for good or ill".

It can be used to explain our perception to the environment. For example, if a surface is nearly horizontal, nearly flat and sufficiently extended and rigid, then the surface has an affordance of support to human and animals. The above properties (horizontal, flat, extended and rigid) are although physical properties that can be measured, they are also relative to human and animals. If the surface is higher than my knees, it is supposed to be seatable for me, however, it is higher than a child's height, it is supposed to be climbable for him. This affordance is not constant, it is a relationship between the observer and the object.

#### 3.2.3.1 Norman's affordance

Affordance was introduced in the field of design by Norman (1988) in his book *The design of everyday things*. He explained the affordance as

"the perceived and actual properties of the thing, primarily those fundamental properties that determine just how the thing could possibly be used".



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The most famous example is the door mentioned by Norman, if the door should be pulled or pushed, the door knob affords two possibilities of action, it could be positive (if the pull is right) or negative (if the push is wrong) (See Figure 13.).

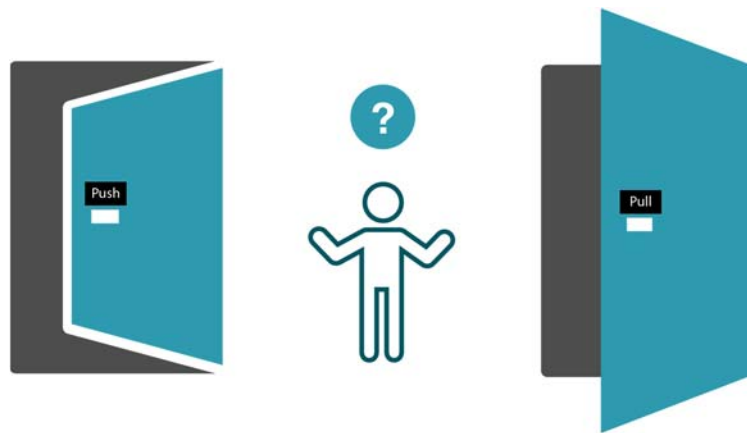


Figure 13. Perceived affordance of the door: push or pull

Users perceive the affordances of the door knob because its attributes relevant for pushing or pulling are available for perception. When apparent affordances suggest different actions for which the object is designed, errors are common, and signs are necessary. What Norman meant initially is the perceived affordances, which is a relation between the person and the object. However, in the user interface design, designers have misused this word to illustrate which part in the interface can be clicked, swiped, or touched. What they really want to express is a cue for how to operate in the user interface. Norman distinguishes the affordance from what the designer mean and he introduced the word "signifier" from semiotics to explain the cued information that can help users to understand the product or service (D. A. Norman, 2008). In this account, we can ask if this means that the perceived affordances refer to the information displayed in the user interface which affords an action.

### 3.2.3.2 Gaver's technology affordance

Gaver (1991) in his article "Technology affordance" has argued that affordance is not passively perceived, but actively explored. The perceptual information may suggest affordances that do not actually exist, while affordances that exist may not be perceived. For example, the door knob affords pulling if the door is locked. He discussed the two kinds of affordances: sequential affordances and nested affordances.

Sequential affordances explain that acting on an affordance reveals the information that indicates another affordance. They are sequential in time. He took the example of the door knob (See Figure 14. a): in which the door knob affords grasping, but the perceptual information may not indicate the affordance of turning it. When grasping the door knob, an exploratory downwards action may reveal a tactile information indicating a new affordance of turning it. Similarly, in a user interface (See Figure 14. b), a dropdown button suggests an affordance of clicking which reveals the dropdown list, and this dropdown list affords another action.

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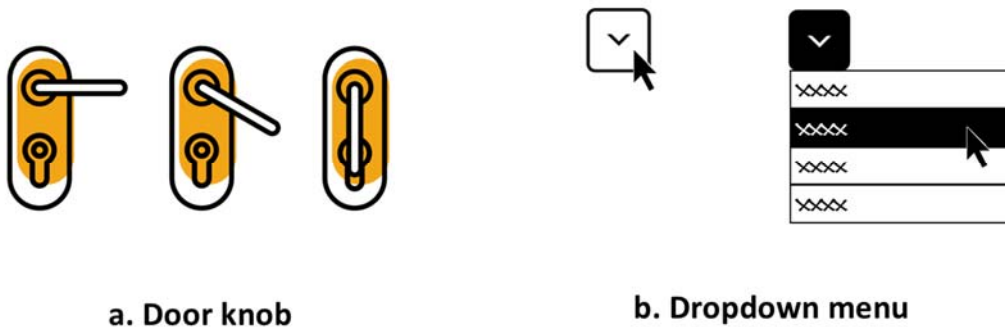


Figure 14. Sequential affordances: one affordance leads to another affordance.

“Nested affordances are grouped in space”. If the door is not nested in a wall, the door alone does not afford pulling. Similarly, a knob alone and not set on a door, does not afford pulling neither. Only when the knob is on the door and the door is nested in the wall, opening the door can be perceived. In this account, the affordance of pulling the knob is nested within the affordance of pulling the door.

McGrenere & Ho (2000) studied Gaver’s work on affordances and emphasized the importance in the affordance of the “function invokability” in design with the example of a button in GUI:

“The button has a clickability affordance, which is specified by a raised-looking push button. But users are not interested in clicking on a button for its own sake; they are interested in invoking some function. It is generally the icon or the label on the button that specifies the function to be invoked. Therefore, button clickability is nested within the affordance of function invokability.”

This emphasizes that not each level of the affordance hierarchy maps to the system functions (i.e. the button itself). They also differentiated the affordance from perceptual information. They pointed out that the affordances allowing users to take actions, which matches their goals to accomplish a task, is about the usefulness of a design. And the design of the perceptual information that specifies these affordances is about the usability of a design. They made this separation because it can help researchers and designers to better understand and clearly distinguish these two kinds of design: usefulness and usability design.

Both Gaver’s and McGrenere & Ho’s works reflect that affordances do not merely suggest the action possibility, but also imply the purpose of an action. With regard to the purpose of an action, there is another principle which explains this in detail.

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### 3.2.3.3 Hartson's cognitive, physical, sensory and functional affordance

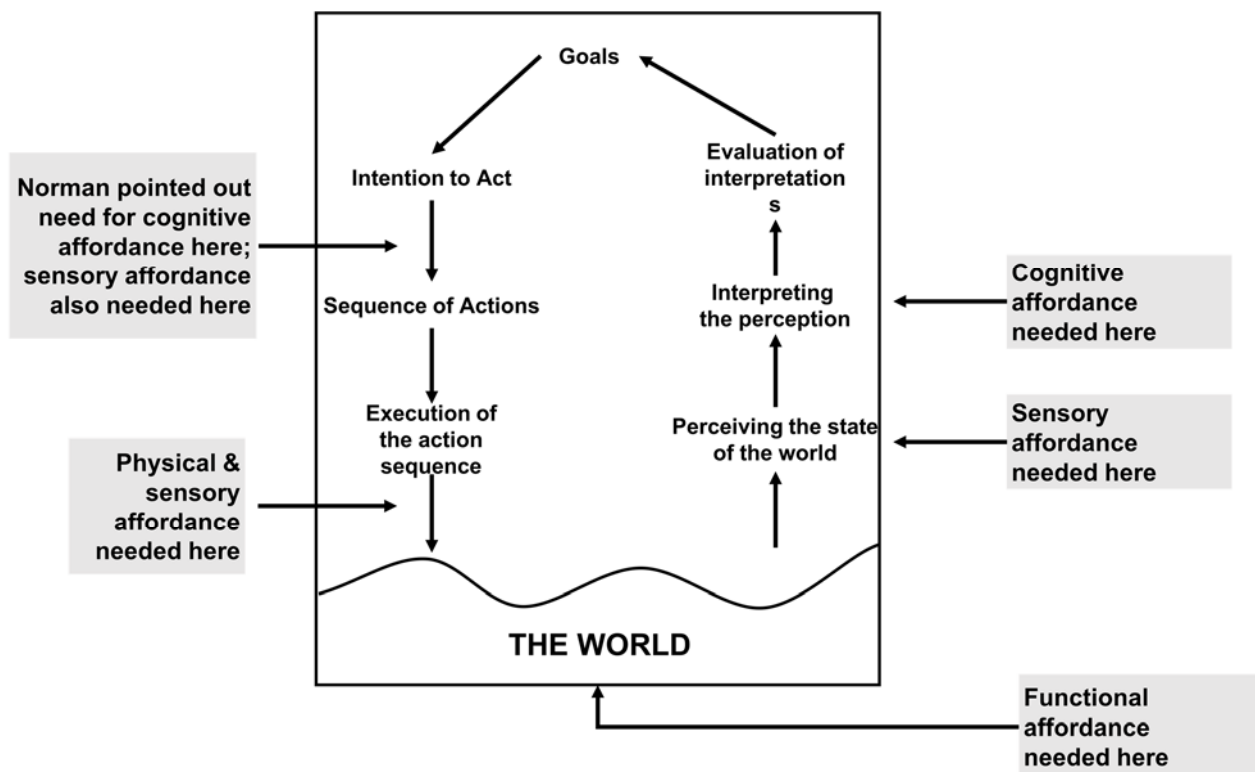


Figure 15. Four types of affordances mapped to Norman's Seven Stages of the Action model (From Hartson, 2003)

Rex Hartson, considers that Norman's perceived affordance is unilateral, and the notion of affordance can be made more specific based on the Norman's stages of action model (Norman, 1988). He proposed 4 types of affordance in the context of interaction design and evaluation (See Figure 15): cognitive, physical, sensory and functional affordance (Hartson, 2003):

- **Cognitive affordance:** refers to Norman's perceived affordance; a design feature that helps users with their cognitive actions, such as thinking, learning, etc. For example, a button label is usually designed representing its function, and the effect after clicking on it.
- **Physical affordance:** refers to Norman's real affordance; a design feature that helps users with their physical actions. For example, designers should consider physical properties of a button, such as the size, position, the shape, etc. in the user interface.
- **Sensory affordance:** refers to a design feature that helps users with their sensory actions. Sensory affordance is a path that can help users recognize information and generate behavior. "For example, a label font size is large enough to be read easily".
- **Functional affordance:** links to usefulness; a design feature that helps users to *accomplish their work*. It is consistent with McGrenere & Ho's idea of affordance matching goals of users to accomplish a task. Such as, "the internal system ability to sort a series of numbers (invoked by users by clicking on the Sort button)".

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Hartson's classification method describes the continuity and logical relationship of affordance. It also highlights the importance of design intention in the process of interaction design.

### **3.2.4 FEEDFORWARD AND FEEDBACK**

Feedforward and feedback are often considered together when we are talking about the information displayed before and after the user's action. Feedback is one of the most common used design principles in the design of interaction as well as affordance (Vermeulen & Luyten, 2013; Wensveen, S., Djajadiningrat, T., and Overbeeke, 2004). Feedback informs the user that the system is responding to his/her request and returning the information indicating the result of an activity (D. N. Norman, 1988). However, feedforward gets less consideration compared with the other two. Feedforward is first defined by Djajadiningrat, Overbeeke, & Wensveen (2002) to distinguish with affordance. As they defined, "feedforward informs the user about what the result of his action will be".

#### **3.2.4.1 Vermeulen & Luyten's feedforward in action model**

Vermeulen & Luyten (2013) reaffirmed the importance of feedforward as a powerful tool in design. They distinguished feedforward from feedback and affordance based on a literature review. Feedforward is mostly about communicating the purpose of the action compared to perceived affordance, which suggests actions. They also positioned feedforward and feedback in Norman's stages of action model and indicated the correspondence of feedforward and feedback with the cognitive affordance based on Hartson's four types of affordance (See Figure 16).

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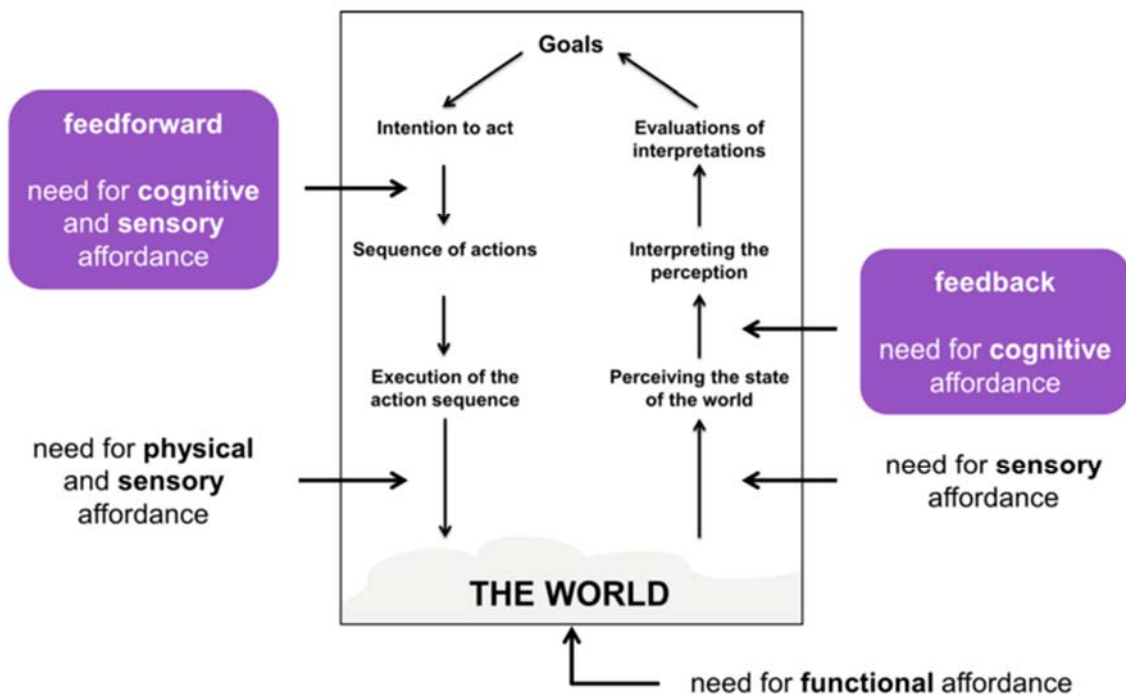


Figure 16. The position of Feedforward, Hartson's four types of affordance and feedback in Norman's Stages of Action model (From Vermeulen & Luyten, 2013)

### 3.2.4.2 Wensveen's direct coupling between action and function

Wensveen (2004) proposed a design framework to analyze the person-product interaction. It focuses on couplings between a person's action and a product's function through feedforward and feedback information: inherent and augmented. He took the example of the scissors in the physical world to illustrate this natural coupling:

"The design of a pair of scissors (appearance) fits our perceptual motor skills. And, when using them to cut paper, moving your thumb and finger towards each other (action) is naturally coupled to a change of orientation of the blades (reaction) and the incision these blades make in the paper (function). When the blades are dull, or the paper is too thick the resistance of the action also informs the user about the failure of making a proper incision."

This coupling of action and function can be realized along six aspects: *time*, *location*, *direction* (up/down, clockwise/counterclockwise, right/left and towards/away), *dynamics* (position, speed, acceleration, force), *modality* and *expression* (Wensveen, 2004). Taking the same example of the scissors: when we cut a paper with the scissors, our cutting action occurs simultaneously with the incision made in the paper – *time*; the act through the scissors is at the same location as the paper is being cut – *location*; our cutting direction is the same as the incision of the paper – *direction*; the faster we move our fingers with the scissors, the faster the incision is made – *dynamics*; during the process, we hear the sound when the blades touch and cut the paper, and we see the incision of the paper – *modality*;

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and if we move the scissors in a hurry that might cause impression actions, it is reflected in the incision of the paper as well – *expression*.

He argued that a proper unification on the user's action and the product's function in these aspects can make the interaction intuitive. This often happens in mechanical products. However, in the interactive information system, it is hard to reach a natural coupling between the action and the function, such as remote control where the location is not unified; the modality is not unified when clicking on a button in the user interface where there is neither sound nor visual effect. Therefore, the author suggested the inherent and augmented feedforward and feedback that guide the user's actions towards the intended function (Wensveen, 2004).

For feedforward

- Inherent feedforward is about what kind of action is possible and how can it be carried out. It can be seen as a limited interpretation of Gibson's affordance.
- Augmented feedforward is about the information indicating the purpose of an action (textual or graphical labels). It helps users understand what is the result of an action, which can be seen as cognitive affordance (Vermeulen & Luyten, 2013).

For feedback

- Inherent feedback is "the information that is returned from acting on the action possibilities and therefore appeals primarily to the perceptual motor skill of the user". For example, when we click on the mouse, we hear a sound from this action.
- Augmented feedback is the information not coming from the action (which is inherent feedback), but from an additional source. For example, if we want to sort a series of number in excel, we click on the sorting icon, and the icon turns to another color, which suggests that the action is done. The color is augmented feedback.

As indicated by Wensveen, in the user interface, the information coming from acting on a physical input device (mouse) is only coupled to the augmented information of graphic user interface (GUI) on the aspect of time and direction. There is a lack of inherent feedforward and feedback in the user interface that we can only rely on, such as a direct coupling between action and function or on couplings through augmented feedforward and feedback. Therefore, when direct coupling cannot be established, augmented information can be used to make the interaction intuitive.

Based on the Norman's stages of action model, the researchers explored the notions of design: affordance, feedforward and feedback, which provide theoretical support to fill the cognitive gaps among designers, products and users. Understanding the relationship among these three design principles is very important for us to design the information, which guides users' actions. This means that the users' actions can be designed to pursuit better user experience in the interactive process.

### 3.3 USER EXPERIENCE (UX)

As social civilization evolves, people's pursuit of psychological needs has become apparent. People began to shift their attention from pure technology to more comprehensive contexts of use and human psychological needs. The American psychologist, Maslow (1943) proposed a theory of human motivation that states that our human is motivated by the desire to achieve a certain percentage of their basic needs. His theory views motivation as a hierarchy of needs that must be satisfied in the following order: physiological, safety, love and belongingness, esteem and self-actualization. As soon as people have fulfilled lower level of the needs in the hierarchy, they will then want to fulfill higher one. Self-actualization is the motivation to develop one's full potential as a human being. When people get used to having something, they then start to look for something more (Jordan, 2000). Taking the idea of Maslow's hierarchy of needs and applying it to human factors, W. Jordan (2000) and Aaron Walter (2011) both translated Maslow's motivation theory to the needs of users for designing products (see Figure 17).

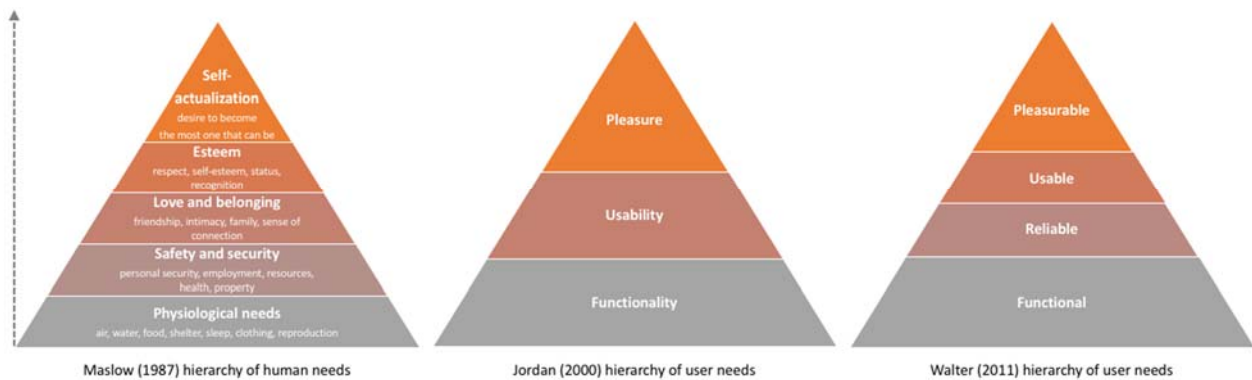


Figure 17. Different views of hierarchy of human needs

Users' needs for various functions in the products have been satisfied with advances in technology. At the same time, the products are becoming more and more complicated to use. Users are demanding more than just functionalities, they are also expecting the ease of use as well as psychological and social needs – the user experience. Hence, user experience determines users' evaluation of a product.

#### 3.3.1 WHAT IS UX?

The word 'user experience' (UX) was introduced and promoted by Donald A. Norman in the 90s. It was invented to take into account all aspects of human experience, which is beyond usability. It is based on user-centered design, focusing on understanding users' characteristics, acquiring user requirements as design decision basis, collecting users' feedback for design evaluation. As a consequence, the interactive systems are designed for a good user experience. For now, there is no consensus on the definition of UX (Law, Roto, Vermeeren, Kort, & Hassenzahl, 2008), but most of the definitions of UX indicate that it is more than the usefulness and usability of a product or a service (Alben, 1996; Garret, 2011; Marc Hassenzahl & Tractinsky, 2006a; Mahlke, 2008b; Don Norman & Nielsen, 2016;

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Schulze & Krömker, 2010). We list several definitions that have been widely used in the scientific community in the following table:

Table 1. Examples of user experience definition

Source	Definition	Complementation
ISO 9241-210	"A person's perceptions and responses resulting from the use and/or anticipated use of a product, system or service."	"User experience includes all the users' emotions, beliefs, preferences, perceptions, physical and psychological responses, behaviors and accomplishments that occur before, during and after use."
Jamees Garret (2011)	"User experience is not about the inner workings of a product or service. User experience is about how it works on the outside, where a person comes into contact with it".	Good user experience must balance the business goal and user's benefit.
D. Norman & Nielsen (2016)	"User experience encompasses all aspects of the end-user's interaction with the company, its services, and its products."	Total user experience is an even broader concept rather than user interface (UI) design.
Hassenzahl & Tractinsky (2006)	"UX is a consequence of a user's internal state (predispositions, expectations, needs, motivation, mood, etc.), the characteristics of the designed system and the context within which the interaction occurs."	Differentiate between pragmatic (usability) and hedonic aspects (emotional impact).
Schulze & Krömker (2010)	"User experience is the degree of positive or negative emotions that can be experienced by a specific user in a specific context during and after product use and that motivates for further usage."	The influencing factors of UX include basic human needs and product qualities.

The notion of UX offers an alternative to the more traditional and instrumental HCI (Lindblom & Andreasson, 2016). From the different definitions of UX, we can see the common and different aspects of UX. We will discuss them in the following parts for a better understanding of UX.

### 3.3.2 THE DIFFERENT ASPECTS OF UX

There have been many studies on UX of interaction, some of them focus mainly on two aspects: pragmatic and hedonic (Marc Hassenzahl & Tractinsky, 2006b; Mahlke, 2008a; Schulze & Krömker, 2010). Pragmatic aspects are related to instrumental qualities (mostly usability) of UX components and hedonic aspects are related to non-instrumental qualities of UX components:



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The *Instrumental qualities* are the qualities that users perceive as useful and usable in the interaction with an interactive system. *Usability* is defined in [ISO 9241-11](#) as “the extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use”.

The *non-instrumental qualities* satisfy users’ personal needs that go beyond the instrumental value of the product (Mahlke, 2008a), such as aesthetic, autonomy, relatedness, innovativeness, originality, etc. These two aspects contribute equally to the overall judgment of product appealingness and thus lead to behavioral and emotional consequences (Mare Hassenzahl, Platz, Burmester, & Lehner, 2000).

Some research works have been focusing on the *emotional aspects* of UX, such as pleasure, fun or flow, etc. (Csikszentmihalyi, 1990; Pieter Desmet, 2010; Jokinen, 2015; Lenay et al., 2007; Mahlke, 2005; D. A. Norman, 2004). Psychologists have offered a variety of definitions and the origins of emotions based on different perspectives in the formation of emotions. There are generally two methods to classify emotions: categorical approaches, which define a set of basic emotions, and dimensional approaches, which divide emotions into several dimensions. For example, Ekman (1992) proposed six basic categories of emotions: surprise, joy, sadness, disgust, fear and anger based on people’s subjective feeling on facial expression. Russell (1980) proposed a dimensional circumplex model of emotions, which suggests that all the emotions can be derived from two dimensions: valence (from pleasant to unpleasant) and arousal (from low activation to high activation) (see *Figure 18*). For example, excited is pleasant in high activation; sad is unpleasant in low activation. The classification helps us understand the different kinds of emotions in human being and gives us a guide to semantically evaluate the kinds of emotions.

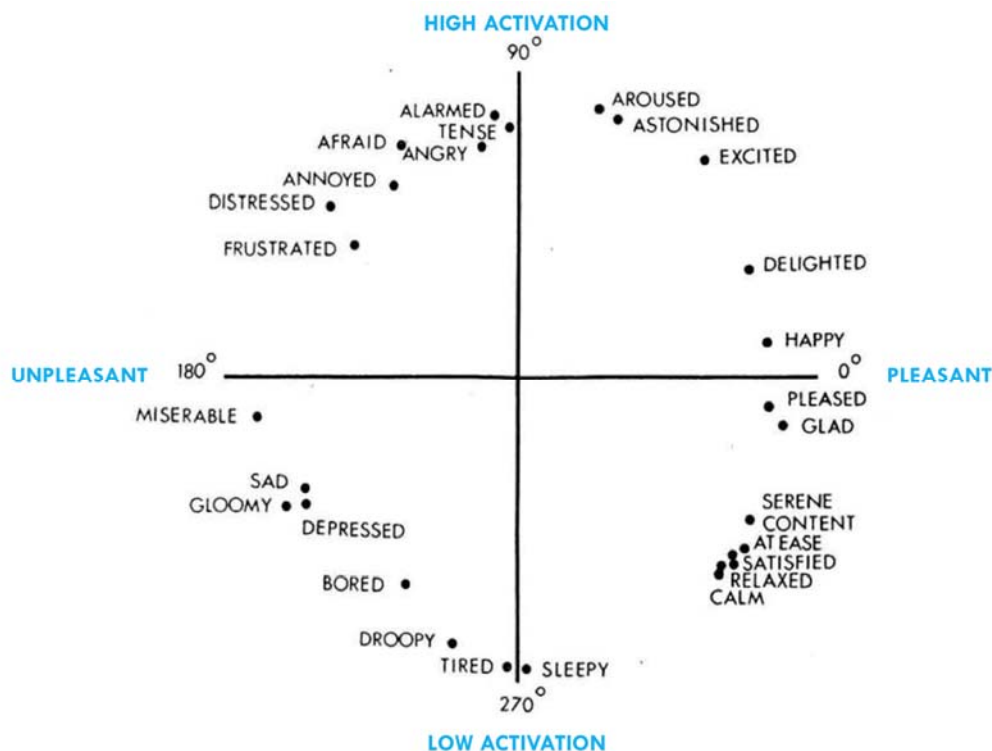


Figure 18. Dimensional approach to emotions (From Russell, 1980)

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Jetter & Gerken (2006) included *organizational values* such as brand identity in their UX framework in addition to functionality, usability and hedonic quality, because they have an impact on the trustworthiness of users. Rubinoﬀ (2004) proposed 4 factors of user experience that are branding, usability, functionality and content. These four factors together determine the success of a website. Brand aspects can also affect UX, because they “are related to the marketing and the business communication between the user and the organization” (Zarour & Alharbi, 2017).

The objective of our research work is to focus not only on the evaluation of functionality or usability, but also on the entire aspects of UX, which includes all these aspects described above. Among them, emotion is a particular aspect of UX, which is presented in the following part.

### 3.3.3 EMOTION-RELATED DESIGN APPROACHES

#### 3.3.3.1 Donald Norman three levels of emotional design

“Emotional design” was first coined by Donald A. Norman in his book *Emotional Design: Why We Love (or Hate) Everyday Things*, and he proposed a model of three levels of design, which is closely related to emotions: visceral, behavioral, and reflective (Donald Norman, 2004).

- The *visceral* level is quite on the surface, innate and biological. It precedes consciousness and thinking, which does not need to be interpreted, nor compared. It only relates to the surface appearance of objects, like physical features: look, feel and sound. It permits rapid judgements of what is good or bad, etc., which is the start of affective processing (N. A. Norman & Ortony, 2003).
- The *behavioral* level is all about use and experience with a product. The experience itself includes three components: function, performance, and usability. A product that can meet all user’s needs is functional. How well the produce can be used is performance. Usability is about the ease of use, which doesn’t need a long time for practicing. A well-designed application can make the user enjoy and get the work done quickly. On the contrary, the user will get angry at the application that lets him/her down and will not use it again. These reactions derive from the behavioral level, where the application fails to live up to expectations of what his/her routine interactions with an object ought to be. Moreover, these behavioral routines are learned. Both visceral level and behavioral level appeal to the subconscious of the user. This varies with person and culture.
- The *Reflective* level is about message, culture, and meaning of the product or its use. It incorporates a sense of feeling derived from affective components at the visceral and behavioral levels along with an interpretation of this feeling (N. A. Norman & Ortony, 2003). A simple example is Apple computer corp. People like to use apple products, because they are first attracted by their simple appearances, then satisfied

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with their use, and finally engaged by their good user experience, which makes them to recommend the Apple products to others. Reflective design is really about long-term customer experience. It is influenced by knowledge, learning and culture.

This model proposes that emotions play a role at all three levels of information processing, and these three levels, from the user's perspective are where designers should be engaged in considering correspondingly the different aspects of a product correspondingly.

### 3.3.3.2 Flow theory

The Hungarian-American psychologist Mihaly Csikszentmihalyi proposed the conception of flow in his book *Flow: The Psychology of Optimal Experience* (Csikszentmihalyi, 1990), which he defines as:

“The state in which people are so involved in an activity that nothing else seems to matter; the experience itself is so enjoyable that people will do it even at great cost, for the sheer sake of doing it.”

He also discussed the 8 major components elements that generate the phenomenology of enjoyment:

1. We have a great chance (skills) to complete a challenging task.
2. We are highly concentrated on doing one thing so that “we stop being aware of ourselves as separate from the actions we are performing”<sup>5</sup>.
3. The task has a clear goal.
4. The task provides an immediate feedback.
5. When we are involved in a task, we can forget effortlessly the worries and frustrations of everyday life.
6. We have a sense of control over what we are doing.
7. Self-consciousness disappears.
8. The sense of the duration of time is altered. Our perception of the time is usually faster than the real one.

These 8 components are concluded from large amount of case studies of the author, which are not limited to user experience. According to Mihaly, the combination of these elements (not necessarily all) causes a sense of deep enjoyment. Some of them can be referred to the evaluation of the UX.

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<sup>5</sup> This is similar to Lenay's sensory-motor coupling. That the tool is a part of our body to do an action, and the tool disappeared from our consciousness when we are in the “in hand” mode.

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### 3.3.3.3 The appraisal theory

The appraisal theory emphasizes that emotion process starts with an event and ends with an appraisal. Our appraisal evaluates the goal and value congruency of the event and establishes how the event meets the goal of a subject. P Desmet & Hekkert (2002) have established a basic model of product emotions that represents the emotion elicitation process. This process sets forth four main parameters: appraisal, concern, product and emotion (See Figure 19). The first three parameters and their interplay determine if a product evokes an emotion and if so, what is its kind. For example, if a user interface meets or is higher than the user's expectation, it leads to a positive emotion. On the contrary, if the user interface does not meet and is lower than the user's expectation, it leads to a negative emotion.

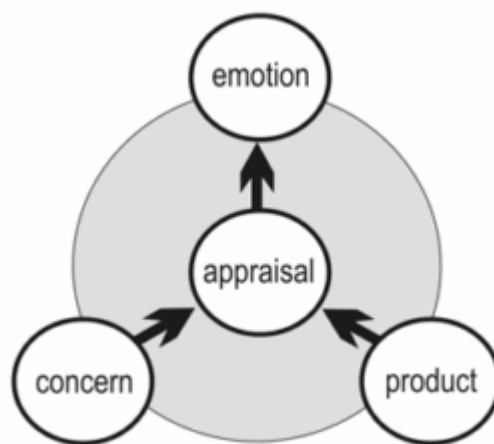


Figure 19. Basic Model of Emotions (From P Desmet, 2003)

The appraisal theory explains the elicitation of various kinds of emotions which is determined by a concern match or mismatch. The appraisal (assessment) is a consequence of the interaction between one's concern and one's perception of product qualities. However, this does not address the process of emotion experienced in the interaction. In other words, how do people experience emotions as they interact with a user interface? I will introduce next the theory of perception (action-sensation perception) and affective interaction design approach derived from the theory.

### 3.3.3.4 Affective computing and affective interaction

The original vision of affective computing is that people are trying to recognize what are users experiencing when interacting with the systems and their emotional responses to the interaction. This notion was first stated by Rosalind Picard in her book called *Affective Computing* in 1998. A branch of affective computing studied whether it is possible to recognize a person's emotions using by analyzing facial expression, bodily gestures, or putting sensors on the skin to recognize our physical reaction to emotions. They are more interested in modeling emotions, which reduces emotional experience to some variables for recognizing and generating emotions.

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Instead of putting more emphasis on the system or computer that knows what people's emotion is based on a model that computes the emotion, another branch emphasizes the importance of the interaction where emotion is constructed, interpreted, and given meaning in a given dialog between a user and a system or between users through a system (Höök, 2011). They call it *Affective Interaction*, which regards emotion as a constructed process that creates meaning between us. A computer system can support people in understanding and experiencing their emotions (Boehner, DePaula, Dourish, & Sengers, 2007; Hook, 2009). They offered an interactional approach to emotion and studied its role in action and interaction.

According to (Boehner, DePaula, Dourish, & Sengers, 2005), affect is often seen as another kind of information – individual's internal state, which operates in the context of traditional cognitive behavior. However, it fails to consider "an understanding of everyday action as situated in social and cultural contexts that give them meaning". In contrast, the interactional approach emphasizes emotions as a social and cultural product experienced through interactions – emotion as Interaction.

### 3.3.3.5 Discussion

In the thesis of A. Guénand (2010), she provided a new perspective of reviewing design methods based on Lenay et al.'s "put down" and "in hand" modes of an object. She stated that there are numerous design methods orienting in the design of an artefact, which is perceived as an object in the environment ("put down" mode), while there is a deficit in the design methods orienting in mastering the attributes of the object as a coupling device. Therefore,

- the appraisal theory evaluates the elicitation of emotions as a congruency between the user's concern and product value, which regards the product as an object in the environment. It is much about the design of an artefact which facilitates the "put down" mode of object.
- perceptual supplementation and affective interaction are talking about emotional values as a result constructed in the interaction with the world, which treats the object as a coupling device, an extension of human. This is typical when the object is in the "in hand" mode.

In this thesis context, we are interested in the design for emotional experience, which is constructed in the interaction through which we are in the "in hand" mode relationship with the system. This is fundamental to our design research as we can design for a type of interaction and invite the user to actively involve and engage in the interaction with an interactive system.

In this research context, we consider the term UX as an umbrella that covers all aspects of user interaction with an interactive system, including usefulness, usability and emotional experience. Then, UX can be measured based on the above aspects, and the measurement methods are introduced in the next section.

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### 3.4 UX EVALUATION

The interaction process is not just a series of performing tasks mechanically to achieve the goal, but an experience with complex emotions and psychological activities through expression and behavior. In the research works on user evaluation methods, cognitive and emotions factors have received as much attention as usability and are even considered as more important evaluation factors. In general, there are subjective and objective method to evaluate UX.

#### 3.4.1 SUBJECTIVE EVALUATION

The subjective evaluation method is widely used as the most direct evaluation method. It is a method in which the user directly evaluates the information interaction process, and generally uses a psychological measurement scale, a user interview, etc. This method is useful for obtaining user motivation, belief, and attitude data. Some practical psychological measurement methods are applied to the user experience evaluation.

There are some commonly used subjective evaluation methods that measure UX from its different aspects (i.e. usability, emotions, etc.) we list these in the table below:

Table 2. Commonly used subjective evaluation method of UX

Method	Description	Measurement	References
System usability scale (SUS)	A "quick and dirty" tool for measuring usability.	Usability	Brooke (1996) J. Bosley (2013)
User engagement scale (UES)	Focus on interaction, including user's evaluation of the system, user's personal thoughts, emotions, and activity.	Aesthetic Appeal (AE)、Endurability (EN)、Felt Involvement (FI)、Focused Attention (FA)、Novelty (NO)、Perceived Usability (PUs)	Heather L. O'Brien & Toms (2012)
Cognitive absorption scale (CAS)	Individual's cognitive focus in the experience.	Temporal dissociation, focused immersion, heightened enjoyment, control, and curiosity	Agarwal & Karahanna (2000) O'Brien & Lebow (2013)
AttrakDiff	To evaluate the perceived pragmatic, hedonic qualities and attractiveness of an interactive product with semantic differentials.	Pragmatic: confusing, impractical, complicated, etc. Hedonic: dull, tacky, cheap, etc. Attractiveness: good, beautiful	(Marc Hassenzahl & Monk, 2010)
Modular evaluation of	A questionnaire based on component model	Usefulness, usability, visual aesthetics, status, commitment,	(Minge, Thüring,

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key Components of user Experience (meCUE)	of user experience from Mahlke & Thüring (2007)	emotions, product loyalty, intention to use, and overall evaluation.	Wagner, & Kuhr, 2016)
The Positive and Negative Affect Schedule (PANAS)	To evaluate the different emotional responses. Positive and negative emotions each have ten measurements.	Positive: attentive, active, alert, excited, enthusiastic, determined, inspired, proud, interested, strong Negative: hostile, irritable, ashamed, guilty, distressed, upset, scared, afraid, jittery, nervous	Crawford & Henry (2004)
Self-assessment-manikin (SAM)	A series of emotional states in three dimensions: valence, arousal and dominance with cartoon characters.	Pleasure: happy, annoyed, unsatisfied, melancholic, despairing, bored Arousal: relaxed, calm, sluggish, dull, sleepy, unaroused Dominance: controlled, influenced, cared for, awed, submissive, guided	Bradley & Lang (1994)
Product Emotion Measurement Tool (PrEmo)	It uses animated cartoon characters with sounds to measure 7 positive and 7 negative emotions.	7 pleasant (desire, pleasant surprise, inspiration, amusement, admiration, satisfaction, and fascination) 7 unpleasant (indignation, contempt, disgust, unpleasant surprise, dissatisfaction, disappointment, and boredom)	(Pieter Desmet, 2003)
Geneva Appraisal Questionnaire (GAQ)	To assess the users' appraisal process of an emotional episode through recall and verbally report.	Novelty, intrinsic pleasantness, goal significance, coping potential and compatibility with standards.	(Scherer, 2001)

These methods are usually suitable for measuring the UX aspects on which they focus, in a valid and reliable way. We can use one or several of the above mentioned scales or part of a scale to investigate the overall experience in a specific situation, such as exploratory search (Heather L. O'Brien & Toms, 2012), online news interaction (O'Brien & Lebow, 2013), etc.

The subjective evaluation method is usually in the form of a survey, which is simple, easy to do and can effectively output qualitative evaluation results. Common survey methods include questionnaire and interview, focus group, and thinking aloud methods (Lewis, 1982), explaining interview<sup>6</sup> (Vermersch, 1996). In the specific design evaluation process, one of the above methods can be used alone, or several methods can be used simultaneously for assessment.

To increase the ample, and improving the data accuracy, Likert scale and semantic differential are the two classical rating scales. The Likert scale is usually described by a survey question with a range of answer options – from one extreme attitude to another, like

<sup>6</sup> "Entretien d'explicitation" original in French by Pierre Vermersch

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"strongly agree" to "strongly disagree". The user can give their degrees of opinion on their perception of a product, such as "the layout of the interface is reasonable and clear." The semantic differential scale, on the other hand, places a pair of exactly opposite adjectives at both ends of the scale's minimum and maximum values, which the user can choose. An example of these two questionnaires are shown below (See Figure 20)

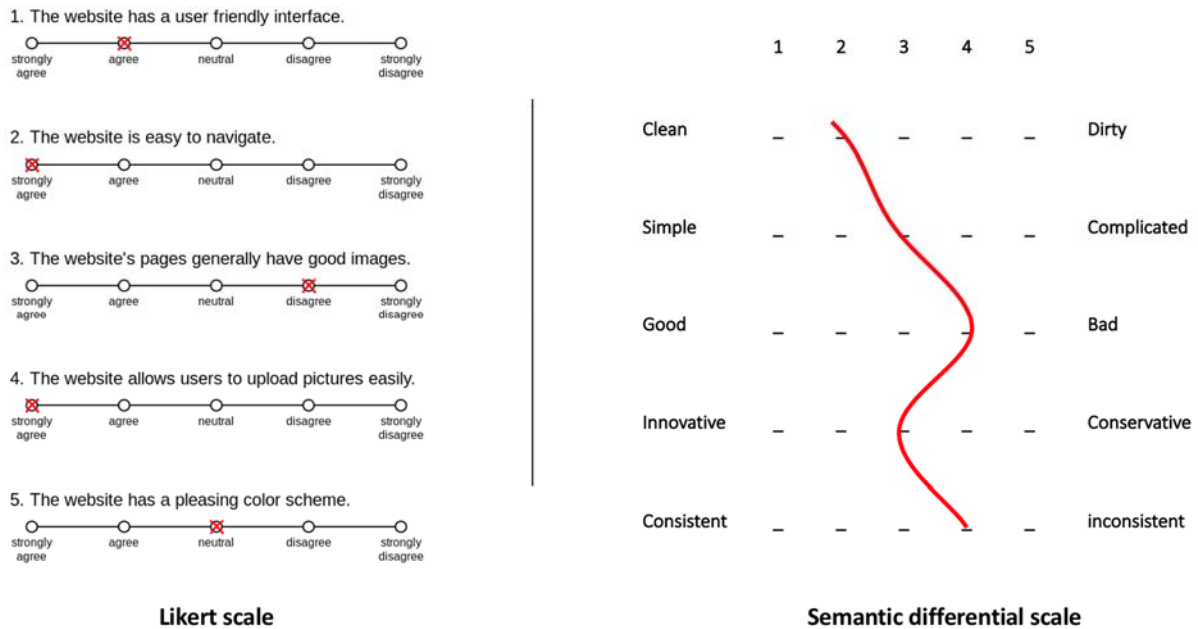


Figure 20. Example questionnaire about a website design, with answers as a Likert scale and semantic differential scale (images from Wikipedia)

The subjective evaluation method is only based on the user's self-report that could have some deviations from the acquisition of data. The results of the investigation may be subjected to the method, the environment and other effects.

### 3.4.2 OBJECTIVE EVALUATION

The objective evaluation of UX involves user behavior and physiological reactions. Its application in the evaluation of UX is less used than the subjective evaluation. These two methods are briefly introduced here.

#### 3.4.2.1 User behavior

Behavioral tendencies are often related to the performance of completing a task, like the completion rate, the speed, the time to spend on the task and task performance, etc. It is proposed by Czerwinski & Horvitz (2002) to measure the task difficulty. The subjects were asked "how long do you think you spent on the task" and it was compared to the actual time spent on the task. It has been shown that people tend to overestimate the duration of task if it is difficult (perceived duration is longer than actual time), and vice versa. In addition, the development of Internet technology has also made it possible for researchers to acquire



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users' behavior data such as track length, dwell time, web pages browsed, usage frequency, log data, etc. (Lehmann, Lalmas, Yom-tov, & Dupret, n.d.; Singla, Vv, & White, 2010).

The behavior data provides a reference for the design and evaluation of user experience. These measures are also used to try to study user engagement (Lehmann et al., n.d.) and emotional experience (Kim et al., 2008). Although it allows to measure user behavior by acquiring a large number of data, the emotions, motivations, and goals cannot be explained and evaluated. It is necessary to use a combination of subjective evaluation methods to interpret the objective data. For example, Picard & Daily (2005) hypothesize that this indirect measure was related to frustration, which was also influenced by task difficulty and other factors, such as time pressure and irritating aspects of the task. This kind of measurement is indirect and cannot fully understand emotions. It can be used and combined with other methods. For example, subjective questionnaire or people's verbalization can help interpret emotional effect related to the task performance.

#### 3.4.2.2 Physiological reaction

Physiological measurement methods have begun to be used as auxiliary methods in human-computer interaction to evaluate information system and study users' emotions (Lopatovska & Arapakis, 2011). The use of this method can permit to capture the physiological response data that researchers and subjects cannot objectively observe. Physiological reactions are often measured with specialized equipment.

There are several physiological methods that can be used for the evaluation of user experience in interactive systems: electromyography (EMG) to measure spontaneous muscle activity; blood pressure to measure the relationship between the dilation of blood vessels and emotions; heart rate (HR/HRV), associated with fear and angry emotions or an increase in cognitive needs; eye tracking to reveal human behavior behind design issues. Due to the introduction of wearable and non-contact physiological assessment devices, the participants complete a task in the interactive system in a natural state, which does not have any influence on the main test. Theoretical research and scientific experiments have confirmed that the data acquired is directly related to user's interaction strategies and cognitive mechanisms, such as eye tracking (Lew & Delivered, 2009; Romano Bergstrom, Schall, & Burrige, 2014; Tzafilkou & Protogeros, 2017; Zagermann, Pfeil, & Reiterer, 2016). We present in the next section how to use eye tracking method to measure the user experience, because it will be one of our means for collecting data in our experiments.

#### 3.4.3 EYE TRACKING

Eye tracking is a technique to track individual's eye movements for researchers to understand where the user is looking at, how long he or she is fixing at specific area and the eye path from one location to another (Poole & Ball, 2005). Since self-reporting tools such as questionnaires may produce biased or even wrong data, eye tracking is to answer the

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questions that the interview and questionnaire are not able to raise. Nowadays, it has been used for an in-depth investigation of general problem solving.

Eye tracking is becoming a popular tool for UX and HCI researchers to evaluate and optimize user interfaces and user experience, because it can provide objective data that reveals user behavior behind usability issues.

### 3.4.3.1 Eye tracking experimental design

When designing an experiment using eye tracking device, 6 steps are usually taken to build a formal experiment (Duchowski, 2007):

1. *Hypothesis*: one of the first considerations is to formulate a hypothesis. It is important to think about what are the kind of data that the eye tracker is able to provide, e.g. fixation, fixation duration, etc. For example, I wonder what would happen if ...; or I bet this result would happen if ... It is important to think about what kind of data that the eye tracker is able to provide, e.g. fixation, fixation duration, etc.
2. *Design*: which experimental design is chosen, an experimental or a non-experimental design?
3. If it is a non-experimental observational study, it is performed to formulate an initial impression of how people may look at some visual stimulus. For example, eye movements collected over an interface of a prototype may lead the designers to focus on the layout. Similarly, in the case of a website page, advertisements or other visually rich media may be evaluated in this manner.
4. While in an experimental design, we should set independent variables (IVs), dependent variables (DVs) and secondary variable<sup>7</sup>. How the participants are grouped should be also considered. The general rule of thumb is to vary one variable while keeping other variables constant and ensure that all other conditions are equal except the main effect suggests gaining control of the experiment.
5. How to plan the experiment is an important question. Whether they are conducted within-subjects (all the participants do the same task, repetitive) or between-subjects (different groups do the same task) depends on the operationalization of the independent and dependent variables and other constraints of the experiment (e.g., time and money).
6. *Participants*: how many participants should be recruited in the study and their demographic information such as age, gender etc. In terms of the number of participant needed, it is dictated by desired output (Pernice & Nielsen, 2009). For

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<sup>7</sup> Secondary Variable can affect the relationship between the DV and other IV of primary interest. It can be controlled during the experiment.

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example, the recommended number of test participants for a heat map is 30 to ensure a good eye tracking data.

7. *Apparatus*: the device to use in the experiment, video-based, combined pupil-corneal reflection; the accuracy, the calibration, etc. To make clear the parameters of the eye tracker device that you are going to use.
8. *Procedures*: if certain instructions or any training are needed (the script to read), what type of calibration is used, etc. Always disclose that you will be using technology that enables you to track the participants' eyes during the session but not to highlight eye tracking topic too much as it can have adverse effects. For example, we would like to test "attentional quality" of a banner advertisement on a web page.
9. *Tasks*: the eye movements are known to be task-dependent. The researchers should define a protocol of what tasks do participant do.

It is suggested to use retrospective thinking aloud (RTA) method for eye tracking studies compared with concurrent thinking aloud method used in traditional usability study. As concurrent thinking aloud (CTA) allows the participants to verbalize what they are thinking about and doing during task execution, it will distract their concentration and influence their task performance and response (Andrzejewska & Stolińska, 2013; Røsand, 2012). In retrospective think aloud (RTA), the participants are asked to verbalize their thought after task completion. The most used retrospective thinking aloud method is cued RTA, where the participants are presented a replay of their actions during the task completion and are asked to talk about what they were thinking at the moment. For example, in the study of the experience of museum visitors, the authors developed a method called REMIND (Reviviscence, Experience, Emotions, sEnse MAKING micro Dynamics), which allows visitors to describe the articulation of their experience in its emotional, perceptual and cognitive dimensions (Schmitt & Aubert, 2017). The visitors are asked to verbalize their experience during a stimulated reviviscence interview (or *entretien en reviviscence stimulée*). This interview is stimulated by videos recording the traces of their initial visiting activity, the one of which the authors seek to understand the articulation, then analyze within an informational structure. This method helps understand how people construct their sense-making in decision-making process. Studies has shown the validity and reliability of RTA in usability and user experience research (Eger, Ball, Stevens, & Dodd, 2007; Guan, Lee, Cuddihy, & Ramey, 2006).

#### 3.4.3.2 Eye tracking measures

In usability testing, we can track participants' eye movement patterns and fixations to understand how they complete a task. The results obtained from an eye tracker can be both numerical data and visual data (gaze data, heat map, clusters). When evaluating usability or user experience, eye tracking data should be combined with other methods, because the eye movement data only cannot be interpreted correctly without the participants proving context (Tobii Technology, 2009).

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We often use some main measurements to study a problem: *fixations* and *saccades*. *Fixations* are eye movements that stabilize the retina over a stationary object of interest. A fixation is the period of time where the eye is kept aligned with the target for a certain duration, allowing for the image details to be processed. *Saccades* are rapid eye movements used in repositioning the fovea to a new location in the visual environment (Duchowski, 2007). The rapidity of eye movements between two fixations can be considered. There are also some metrics derived from these basic measures. Poole & Ball (2005) summarized different eye movement metrics based on the state of the art in HCI and usability research. Eye movement can also provide a study on human cognition especially in the case of problem solving and reasoning process (Andrzejewska & Stolińska, 2013; Zagermann et al., 2016). For instance, users usually focus on relevant parts of the system when doing a task, which might support them in problem-solving and therefore release their cognitive effort (Rudmann, McConkie, & Zheng, 2003). Bojko (2013) listed a taxonomy of eye tracking measures often used in the UX field that they categorized in two aspects: attraction area and performance metrics (Figure 21)

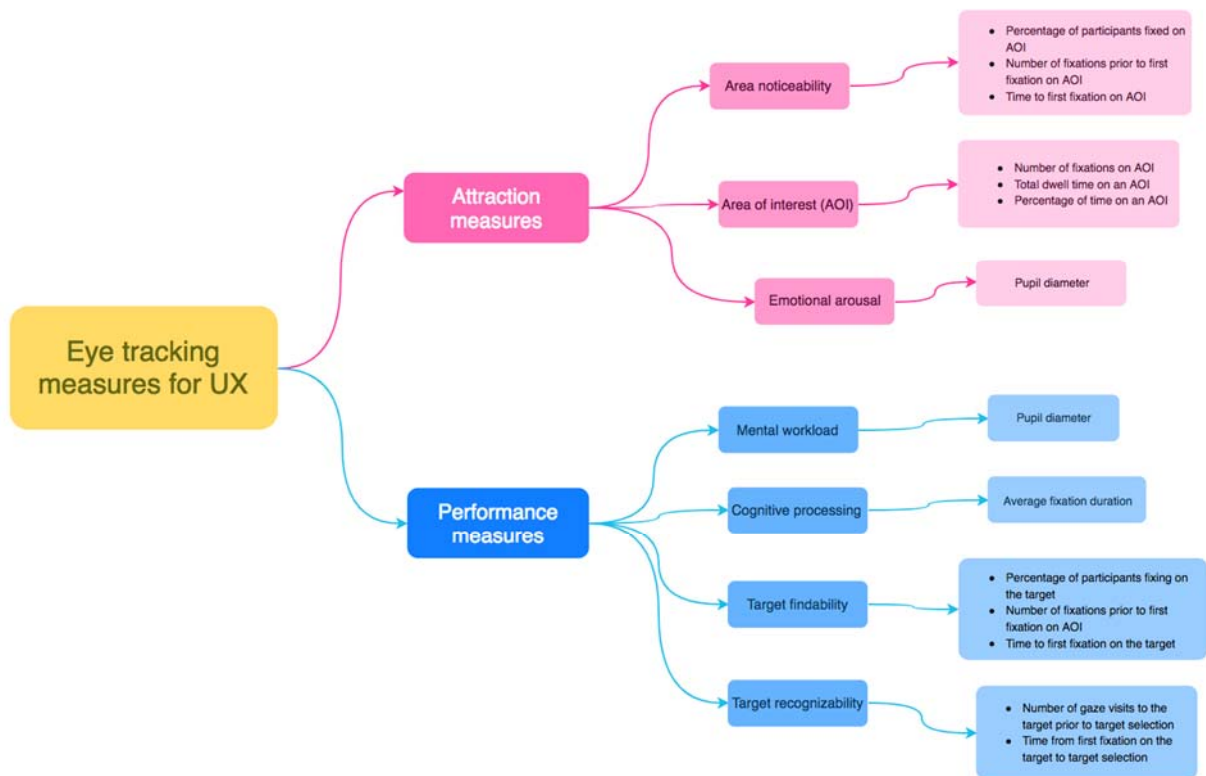


Figure 21. A taxonomy of eye tracking measures for user experience (Bojko, 2013)

The measurement of attraction helps designers understand users' awareness, interest in relation to the design. The measurement of performance determines if users achieve their own goals efficiently, thus helps evaluate the usability of a design including mental workload, search efficiency, etc. These eye tracking measures can be easily referred to by researchers to answer UX questions. They can be interpreted based on the context of use combined with the participants' verbalization reports.

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The complexity of user experience requires a comprehensive research method to measure and evaluate. Subjective evaluation investigates users' motivations, preferences, attitudes, etc. Objective evaluation demonstrates the user experience responses of "what" but cannot reach "why". Therefore, a mix of these two methods is usually used to evaluate the user experience.

### **3.5 CHAPTER SUMMARY**

In this chapter, we reviewed the instrumentation approaches that have been realized for task recovering aid including the history of process (analytic provenance). We also addressed the interaction and user experience design that can be applied for the instrumentation. We have examined the design principles based on the Norman's seven stages of action model: affordance, feedforward and feedback, which we should follow to design the interactions of natural coupling device. We have also studied from a global perspective – user experience design that is beyond usability and its evaluation method from subjective and objective perspectives, which we are going to apply in our experiment for evaluation.

The literature study will allow us to formulate and explore our research problem in this new design perspective and construct our own method adapted to our research context (analytic applications). In the next chapter, we precise our research problem and present the method that we followed to explore it.



## Second part: elaboration and implementation of the research method

*"A plan for arranging elements in such a way as to best accomplish a particular purpose."*

*– Charles Eames, American designer*

*"I don't think that you can invent on behalf of customers unless you're willing to think long-term ... If you're going to invent, it means you're going to experiment, and if you're going to experiment, you're going to fail, and if you're going to fail, you have to think long term."*

*– Jeff Bezos, CEO of Amazon.com, Inc.*

The second part includes 3 chapters: chapter 4, 5 and 6. Based on the review and analysis of the previous theoretical and conceptual work presented in the previous part, we reformulate our research problem that is about the possibility of designing a memory supplementation support to aid and motivate users for recovering a task. We first present the research method that we followed to build this work. We outline the frame of our field study including a user model, a user task. Then, we define the elements for testing the perception of interactive applications from a designer's point of view. To begin with, we construct a questionnaire to evaluate the interactive qualities and the design of a tool taking into account these elements defined above. These experimental data and results let us state for the necessity of testing the extent to which, what we call a history path representing the trace of previous problem resolution steps, can be a candidate for memory supplementation. We implemented it in an experimental environment to test the validity of two main hypotheses of history path used as memory supplementation: static and dynamic. Finally, we applied the history path tool on a professional analytic application.

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## CHAPTER 4 RESEARCH PROBLEM

*"Un problème bien posé est un problème à moitié résolu"*

— *Henri Poincaré, French mathematician*

*"Design principle: define what the product will do before you design how the product will it."*

— *Alan Cooper via Spencer Edwards, American software designer and programmer*

*"Recognizing the need is the primary condition for design."*

— *Charles Eames, American designer*

This research was initiated to assess the extent to which one can propose an interactive analytic tool built on user experience design. For that purpose, we had to build an exploratory prototype to study users' behavior from the user experience perspective. Our general problem is therefore facing the question of the design of perceptual user interface to harmonize with human cognition, particularly with human memory, that we will call memory supplementation. In the preceding chapter, we have considered the theoretical aspects related to the notion of cognition (perception, memory) and human-computer interaction by positioning ourselves in the enactive approach. This allows us to consider the design of a perceptual user interface as a sense making process that emerges from a "in hand" and "put down" mode of the interface. We found the limitations of human's memory that the working memory that we use for the current work is limited in capacity and decays overtime. Besides, the traditional model of memory ignores the embodied view where the interaction plays an indispensable role in the formation of memory. We proposed to complete the traditional model by adding the embodied memory that constructs our connection with the world through the sensorimotor loop. Then, the problem is related to the design for the memory aid as a supplementation to human's memory for achieving complex tasks. This allowed us to investigate the interaction possibilities of two design approaches: the user interface (UI) design, in which the history tool is considered as "put down" in the environment; the user experience (UX) design considered as a coupling device between the user and the world, being the "in hand" mode. We have studied many researches in the design of a provenance tool in the context of task interruption and resumption, from which we discovered the scarcity of the design for the tool in the "in hand" mode that permits a memory supplementation. These current works are generally linked to the provenance tools indicating the history of past actions, which can be perceived

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and acted as in the “put down” mode. In this research, we are aiming at designing the provenance tool in the “in hand” mode (as a memory supplementation), which provides users with more possibilities of actions and makes them aware of unexplored areas. It extends their capability of perceiving the problem-solving as a supplementation of their perceptual systems.

Therefore, we can formulate our research problem as follows:

Is it possible to design a provenance (history) tool that plays the role of memory supplementation, which encourages users to “re-commit” to their suspended or interrupted tasks?

It is indispensable to consider the user interface as a tool in the “in hand” mode in the design, and as such, that the new perception that this tool gives rise to leads to a new perceptual experience.

## 4.1 GENERAL METHOD

### 4.1.1 USER-CENTERED DESIGN

As we presented previously, in this research what we are caring about is beyond the usability aspect of design, but rather the entire user journey – user experience. UX design is still based on user-centered design, which is an iterative process. Then our research is organized around this process: understand the context of use, specify user requirements, design solutions, evaluate the design<sup>8</sup> (see *Figure 22*). It is about articulating the applied research putting the users’ needs at the center of all design. We focus on the design of the applications based on the theoretical questions raised by the use of applications and tested through the experimentation.

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<sup>8</sup> ["User-Centered Design Basics". www.usability.gov](http://www.usability.gov). Retrieved 18 June 2017.

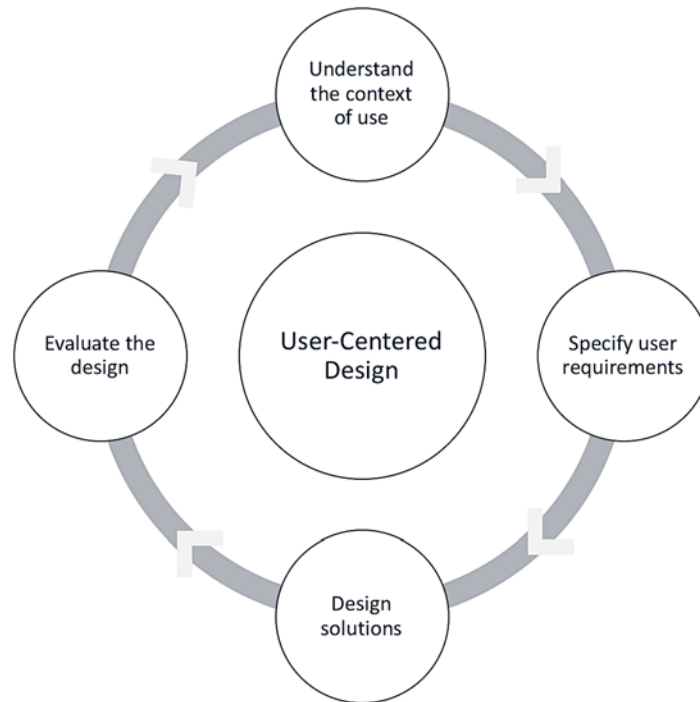


Figure 22. User-centered design process (adapted from [www.usability.gov](http://www.usability.gov))

- *Understand the context of use*: we should identify who are using the product, why they use the product, and in which situation they use it. This is a very important step in the design process as it determines our users and their context of use, which kicks off the research project. This is going to be presented in the next section.
- *Specify user requirements*: we should also identify users' goals, matching the business goals, that can be met to make the product successful. A user study is done to better understand users' needs and pain points in the context of use.
- *Design solutions*: this is a large process, which can contain multiple steps from diverse ideas to end in a high-fidelity prototype ready for test.
- *Evaluate the design*: to test if the design solution can satisfy users' need, or to test if our hypothesis is supported or rejected. We can find in the literature many ways to evaluate the user experience We chose those which are suitable for our experimentation, and they will be presented in the experimentation chapter.

## 4.1.2 DESIGN THINKING

Our research is not to improve a functionality of a product or achieving a goal of a client, but to explore for new knowledge or new concepts that can bring a value to innovative solutions. Creating innovative solutions and products that bring value to users depends on the ability to understand users' needs and determine what will help them to reach their goals. Successful products and services appeal to both the rational side and the emotional side of human intelligence (Mathis, 2011). Design thinking provides an approach for

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balancing these needs. It is a methodology for routine innovation that brings together the right side of the brain (creative) with the left side of the brain (analytical).

Design thinking is an approach to innovation on which many innovative companies have based their business strategy and through which they have developed an innovative way to listen to their customers. They practice design thinking to create the value. Design Thinking is an iterative team-based process for the team to foster their collaboration, creativity and innovation in order to create a solution which best fits the users, the core is to put users in the center of the product development cycle.

SAP collaborates with Stanford DT School and the Hasso-Plattner Institute – School of Design Thinking in order to introduce this methodology in its work culture. It lets us discover opportunities, consider what is possible, find inspiration and create successful solutions that meet human needs, add business value and are technically feasible. SAP is a leader in embracing Design Thinking as a mindset and enabler for innovation on all levels. We chose to follow the design thinking methodology in this PhD. research.

SAP articulates the design thinking in 3 stages: discover, design and deliver.

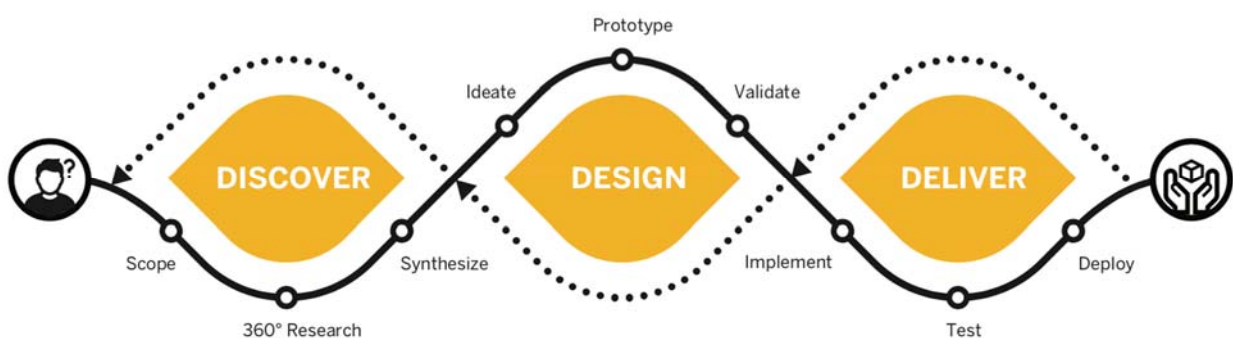


Figure 23. SAP design thinking model

- Discover: the discovering phase is all about understanding. Artifacts generated are personas, articulated user needs, insights and design principles that will continuously guide the project.
- Design: during the design phase we move from the problem into the solution space. We generate ideas and start visualizing them, creating low-fidelity prototypes. We test and validate with users and further iterate.
- Deliver: the deliver phase is about developing functional prototypes by applying technology. Business viability is also taken into consideration. Testing and iterating allow us to continuously keep desirability in mind throughout development.

Design Thinking is a highly iterative process. Once we obtain a feedback, we go back to the user and research their need and figure out a suitable solution. We can go around the process as many times as possible. Wherever we feel stuck, we can jump to either of the blocks and do it again. For example, if we are stuck because we don't have enough ideas, we

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can jump to the ideation part and think about more ideas; or if we are stuck because we misunderstand the needs of users, we can jump to the discover part, etc.

Both user-centered design and design thinking aim at insuring the real needs from users are at the center of the tool created. Design thinking is a specific implementation within the user-centered design framework. We conducted this research work throughout the design thinking method.

## 4.2 UNDERSTAND THE CONTEXT OF USE

As this research is initiated for the design of analytic applications, it is necessary to understand what they are, in which conditions the application is used, and who are the intended users. This information helps us determine the salient characteristics of the application.

### 4.2.1 BI & ANALYTICS DEFINITION

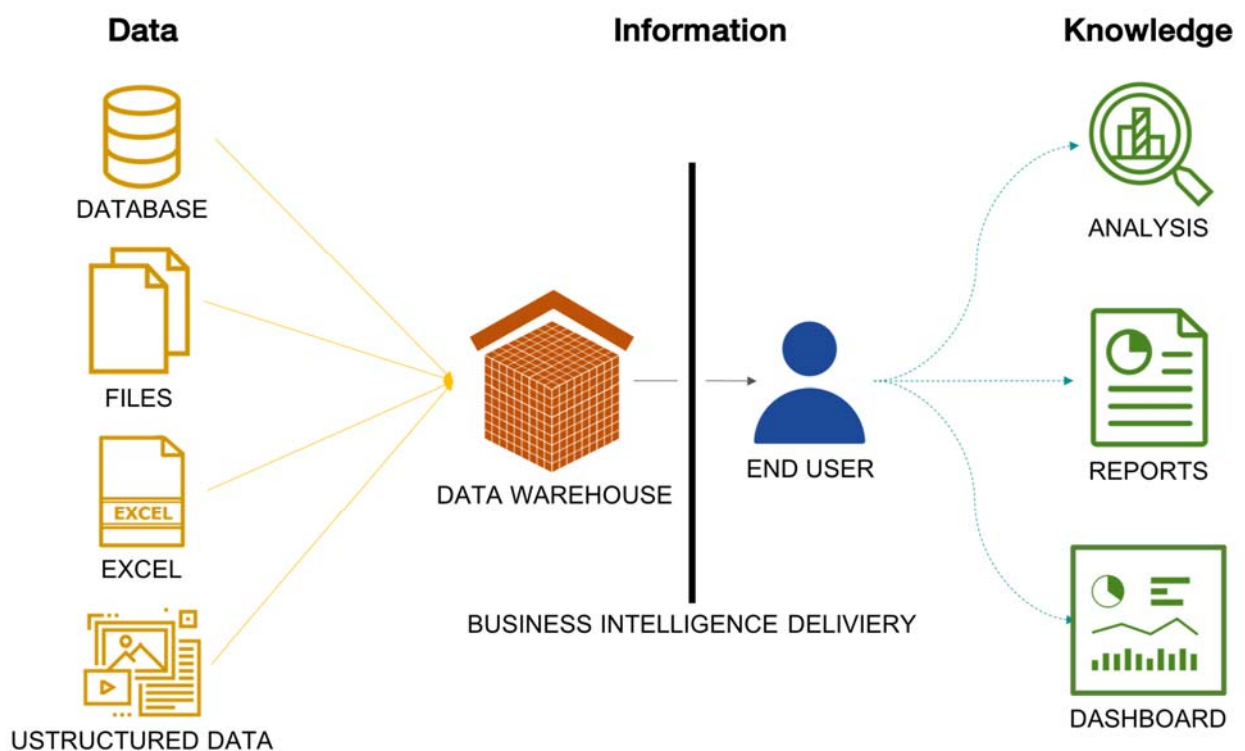


Figure 24. Business Intelligence Schema

Business intelligence (BI) is a technology-driven process for transforming raw data from different data sources, analyzing data and presenting actionable information to help corporate executives, business managers and other end users make more informed business decisions (Rouse, 2017).

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In simple words, the BI process is about taking data and transforming it into information, which gives the end-user insight to make a decision and take an action that brings value (A. Hansen, 2014).

Because of the wide range of BI, it encompasses a variety of tools, such as tools for ad hoc analysis and querying, enterprise reporting, designing charts, building dashboards and visualizations to make the analytical results available to corporate decision makers as well as operational workers.

The benefits of BI involve the optimization of business process, easy interpretation of large volume data, improving decision making, identifying new opportunities and implementing an effective strategy. Thus, it enables the companies to gain a competitive market advantage and long-term stability.

Originally, BI tools were primarily addressed to data analysts and IT users who ran analysis and produced reports for business users. Nowadays, large enterprises extend their strategy to the business users who want to consume information and do ad-hoc analysis, monitor KPIs (key point indicators), and identify root causes for a business questions to facilitate decision-making. The more advanced platforms are gradually becoming *self-service* BI platforms, which enable business users to access and work with various information without IT involvement (except for setting up data warehouse, deploy query, etc.).

### 4.2.2 THE ANALYTIC USER MODEL

The SAP user researchers have created an analytics user model of 5 user archetypes based on field researches and expert interviews with customers. The analytics user model is intended to provide a high-level product guidance, serve as a foundation for personas<sup>9</sup>, and allow us to create a shared language. The 5 types of analytics user models are decision makers, analysts, data scientists, designers and administrators.

Different from personas, analytics user types are defined based the users' intention. Intentions represent a person's business goal and why they are doing something. There are 7 core intentions of BI users: monitor, explore, explain, enrich, design, govern and plan.

- Monitor: to keep track and be notified of the things that matter to the business
- Explore: to find answers to questions and discover new areas of interest
- Explain: to tell a story with data
- Enrich: to add new information and knowledge to existing data
- Design: to professionally author custom BI content

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<sup>9</sup> A persona is a user archetype, a fictional individual derived from real users, needs, preferences, biographical information, and a photo or illustration. It helps a development team to empathize with user (Alan Cooper).






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- Govern: to ensure security, consistency and standards across BI systems and content
- Plan: to align users across the organization to common goals and keep track of stuff.

What each user type does is based on his/her intentions (See Table 3).

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Table 3. Intentions of analytics User Types

USER TYPE	MONITOR	EXPLORE	EXPLAIN	ENRICH	DESIGN	GOVERN	PLAN
 <b>DECISION MAKERS</b>	Stay current on the performance of metrics I care about	Answer a known question I have	Explain to others what I have discovered	Add value to the system through my usage patterns		Securely share information with my colleagues	Set goals for the line of business
 <b>ANALYSTS</b>		Ask complex questions and uncover new patterns	Build a case to convince my boss and team	Manipulate data to make it useful to my line of business		Validate information being created or brought into the system	Validate information being created or brought into the system
 <b>DATA SCIENTIST</b>		Ask complex questions and uncover new patterns in big data	Present and explain the results to team members	Apply predictive models to get very quick responses to questions	Create predictive models and apply them to data sets	Decide the iteration frequency to retain the predictive power and validity of the built models	Choose which data to collect and identify areas to invest in
 <b>DESIGNERS</b>				Define standard entities and structures for the Enterprise	Create standardized data models, metadata, and BI content	Make content consistent and understandable for the Enterprise	Provide assets to support goal setting and execution of the plan
 <b>ADMINISTRATORS</b>					Create user roles	Manage system content and assign user security	



Concerning the 5 analytics user models, we have:

- *Decision makers*: to leverage knowledge for everyday decision-making on how they operate and manage their own activities and that of organization. They will only use BI tools to help them do their job. They rarely do data analysis and just want to see the result, and occasionally drill down the data if necessary. They cannot afford time to learn new tools.  
For example, a decision maker could be a sales manager, marketing manager, and truck driver.
- *Analysts*: to activate data by turning information into actionable knowledge to help organizations better understand their business. Their primary concern is supporting the current goals of their team and they need to quickly adapt as these goals change. This kind of users are capable of performing complex analytical tasks, and they spend the majority of their time in working with numbers.  
For example, an analyst could be a business analyst, marketing analyst, director of operations and chief financial officer.
- *Data scientist*: To address business questions and uncover hidden insights to business challenges, data scientists look at the data from many different angles to understand them and eventually translate them into actionable items for decision makers, thanks to their solid foundation in math, statistics, probability, modeling, analytics and computer science.  
For example, people with a data scientist user type are equipped to analyze big data using advanced analytics tools and expected to develop new algorithms for specific problems. The job title is usually "data scientist".
- *Designers*: to build data assets in a consumable way to enable enterprise-wide information initiatives. They create content according to specification for broad usage across the enterprise, including designing data entities, applications, templates and reports. They employ professional tools, usually within an integrated development environment (IDE), so that they can code, test, fix, save and deploy their solutions.  
For example, developer ETL (extract, transform, load) designer, a BI consultant, a data warehouse architect, a BI architect and an IT analyst.
- *Administrators*: to optimize the BI platform and ensure this system is kept up and run smoothly. They are responsible and accountable for the setup and operations of the system, especially user access and security. They are concerned with managing file versions, and also in charge of the system deployment.

For example, a BI administrator, a platform administrator, a BI architect and an IT analyst.

Note that the analytics user model does not equal to a persona. Different personas can exist within a particular user type or can span across multiple user type. The user types are intended to be more like hats someone would wear. Therefore, a persona can be made up of more than one user type. For example, a marketing analyst often monitors, at that point, they are wearing a decision maker hat; while when they create a new model to analyze complex data, and they are wearing an analyst hat.

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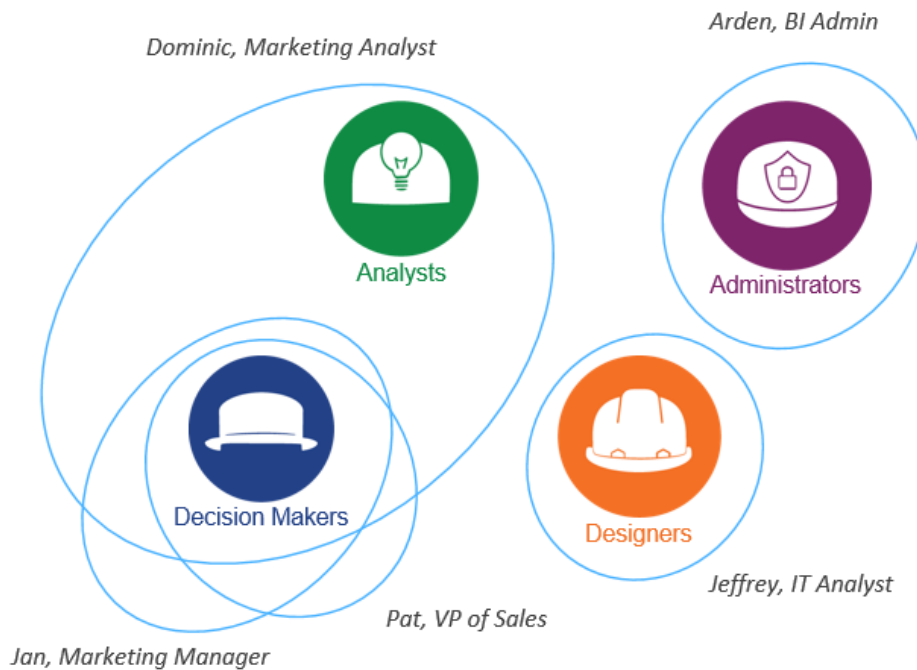


Figure 25. Relation between User Types and Personas: A Persona do not necessary map 1:1 with a User Type; Persona may shift User Types. (Image from SAP)

In this research, we will consider self-service BI for the decision maker user type and the analyst user type. More precisely, we will focus on visual analytics, which is the science of analytical reasoning facilitated by interactive visual interfaces (Thomas & Cook, 2005). Business analysts or data analysts regularly iterate the visual analysis steps for investigating questions and generating hypothesis. To have a better understanding of how people usually do an analysis task and what are their common problems, we conducted an analysis of the users of the company.

### 4.3 USER STUDIES

In the design process, the study of user is a key step to understand user needs, expectations and pain points in order to generate new ideas. Therefore, 7 research studies were conducted in the company on its customers and employees working as users of analytic application. The studies involved several fields of studies (ethnographic, observation, interview, focus group), and usability studies (questionnaire, usability test). The objective was to understand Business users' working context, their needs, expectations and their pain points when using analytic applications.

We summarized the common analytical task scenario (data preparation, data manipulation, data analysis based on visualization, report creation, sharing) and discussed the findings from these user research studies. This study helped us bring out the research problem.

### 4.3.1 METHODOLOGY

7 studies were first conducted from 2011 to 2016 in the company, including the field studies and formative usability studies with the customers and internal employees.

The aim of the strategic phase of the project development, which concerned the field studies, was to find opportunities, generate ideas for solutions and innovations and identify problems. For example, "IDDC" research (see Table 2.) in 2011 used ethnographic and observation studies to identify the barriers of BI software use across a wide spectrum of business users and generate user clusters in terms of their usage of quantitative information. The research on "decision maker persona interview" users used the method of the interview, the observation and focus group to identify the persona(s) of decision maker. These two studies help the researchers to understand users' working environment, their usage of analytical tasks, their attitudes and their pain points.

Formative usability tests are proper to be used during the development of the product. The participants are given a script to interact with BI prototype so that the researchers can get specific feedback for optimizing designs in order to reduce risk and improve usability (Rohrer, 2014).

We categorized them into several aspects, such as the objective of the task, the target user, the procedure, the analytical effort. Then we identified some common points about the analytical task flow and users' expectations about the applications (see Table 2.).

### 4.3.2 ANALYTICAL TASK FLOW

Among their analytical tasks, except for predictive analytics, the participants all have conducted data exploration based on the visualization of charts. The more they do actions of visualizations, the more they have the intention to create a report and share with others. This was discovered implicitly from the studies summarized in Figure 26.

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Table 4. An overview of the 7 research studies

Research Resources	IDDC Research	HILO Desktop Formative Usability Test	HILO Desktop Data analyst research via CEI	Lumira Desktop Usability Test	Smart BI: Lumira for Decision Maker Formative Usability Test	Decision Maker Persona Interviews	Predictive Analytics 3.1 Usability Validation
<b>Date</b>	<b>2011</b>	<b>October, 2011</b>	<b>February 2012</b>	<b>June, 2014</b>	<b>November, 2014</b>	<b>2014</b>	<b>2016</b>
<b>Goals</b>	To determine opportunities and barriers to reach “casual” users with solutions that enable a more engaging use of quantitative information in BI area.	1. To validate user scenario of shaping their data; 2. To gather usability and functionality feedback on Hilo design.	1. To learn about business users' working process, task flows, key challenges and major pain points; 2. To gather usability and functionality feedback on Hilo design.	To gather usability and functionality feedback on Lumira design.	1. To see if the displayed information is well understood. 2. To gather feedback about the root cause analysis workflow based on the search pattern.	To create Decision Maker personas and accompanying scenarios.	To get insight into usability issues by user feedback to influence the product development.
<b>Targeted User</b>	Casual business users	Data artisan (business analyst)	Data artisan (business analyst)	Decision Maker (DM) and Analyst (User type)	Decision Maker (DM — User type)	Decision Maker (DM — User type)	Data Scientist
<b>Participants</b>	<b>54 users</b> (professional analysts, active users and casual users) across a wide spectrum of users in <b>8 companies in different industries.</b>	<b>Pre-event: 3</b> internal participants from Finance and Cross PM organization. <b>Actual event: 10</b> BI experts, at least 5 years of experience in BI.	<b>Interview: 9 participants</b> in Hungary, Germany and the US <b>Usability Test: 11 participants</b> in the US <b>Experience:</b> at least 1 year in the company.	<b>5 participants:</b> data scientist, BI manager, Senior Manager, Corporate Planning Retail Learning Manager, Supply Chain Analytic Manager.	<b>14 participants:</b> BI consultants, experts and BI managers.	SAP internal employees <b>4 managers, 6 individual contributors</b>	<b>6 participants</b> with user profile of predictive analytics (PA) from different industries and companies
<b>Software to test</b>		Hilo Desktop (prototype)	Hilo Desktop	Lumira Desktop	Lumira for Decision Maker (prototype)		Predictive Analytics 3.1
<b>Methodologies</b>	<b>1st phase:</b> more than 50 users <b>2nd phase:</b> 54 interviews with individual users	• Questionnaire for user profile. • Usability Test	• 9 interviews (guide) and observations • 11 usability validations activities	• Background questions • Usability test • Free exploration of Lumira (“free play”).	• Interview • Test scenario	• Interview • Researchers rotated roles	• Background information • PA concept introduction • Usability test • Post survey

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Figure 26. Analytical task flow

1. In data manipulation, the participants do simple actions on the data, such as create a hierarchy of date (year → quarter → month → day), geography (continent → region → country → city), etc.
2. Visualization building: users choose the proper charts for each visualization.
3. Report Creation such as storyboard or infographic.
4. Sharing: users share their reports to their upper manager or colleagues.

### 4.3.3 PROBLEMS OF ROOT CAUSE ANALYSIS

In a self-service BI task, the most important part is data analysis based on visualization. Some operations are necessary for this kind of analysis, such as navigate, filter, sort, drill down, search, annotate, create new visualization.

From these studies, we observed that, since most of the users do not have an IT background, they tend to conduct a simple analytical task based on the visualization. During this process, their adopted strategy is similar to that we adopt to solve every day problems – *root causes analysis*. It is a method of problem-solving used to identify the causal factors to a problem (Paul F. Wilson, 1993). In the BI context, root causes analysis is a strategy that business users apply in the visual data analysis to identify the root causes of a business question.

Consider, for example, a common visual analytics task: Jim is a sales manager (decision maker user type), he needs to investigate the root causes for the sudden increase of the sales returns in March 2014. He starts from a “returns by month” visualization. Then he clicks on March 2014 data point and expected to be able to “drill” from this point, which means isolate noteworthy data point as filter and breakdown with another dimension like “Product” to see if the peak of returns is concerning specific type of product in this March 2014 context. This is producing a new visualization where a certain product appears as an outlier. From this, he repeats the same process, drills down in the product outlier, generates another hypothesis that perhaps is related to product quality, tests the hypothesis until he finds out the possible root cause. However, it is common to have multiple causes to the same problem, then returning to a previous visualization and trying another hypothesis (for example, store service) is also possible. This is often an iterative analysis, which includes a series of steps to go back and forth to create several visualizations until one finds

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the root causes of this change in sales returns (4.).

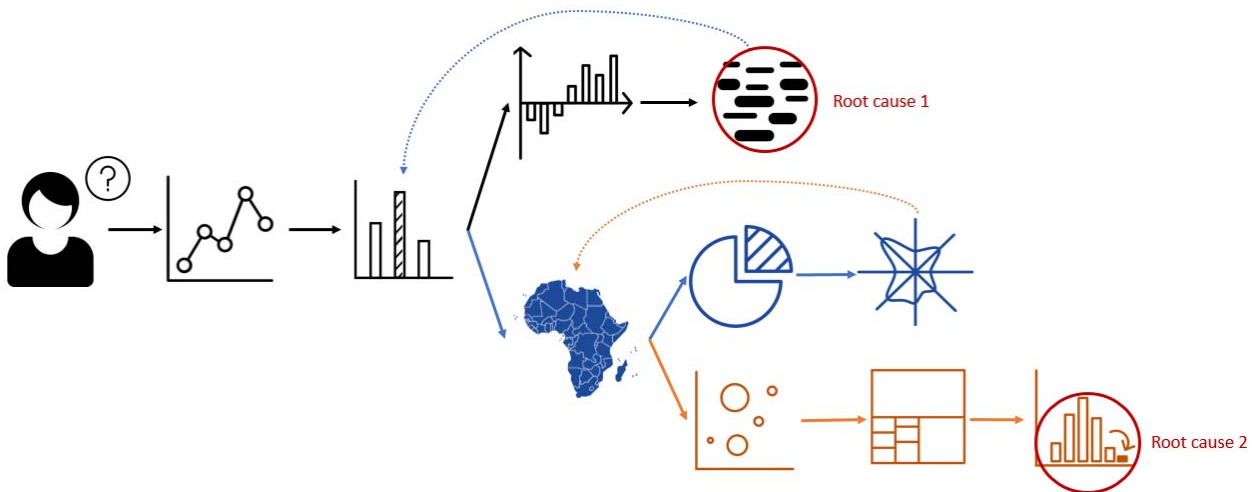


Figure 27. Root cause analysis in the visual data analysis, the dot line represents the return to a data visualization to start another analysis path.

According to the participants in several studies, they expressed the need to have a dedicated area where all previous steps could be stacked, and which enables them to “undrill” to go back to the previous visualizations for exploring another path or for similar issues

#### 4.3.4 ROOT CAUSE ANALYSIS: DESCRIPTION OF THE PROBLEM REGARDING USER EXPERIENCE

As shown in the previous section, the users use a root cause analysis strategy to conduct a visual analysis task. They get used to keep track of what they do for every step for testing a given hypothesis or generating some results during a visual analytic process. There are three conditions for which analytic provenance can be applied in the root cause analysis.

- The analytic process is complex with large size of datasets and the hypothesis to test. There could be more than one root cause, which means more than one analysis path (Figure 27. Blue and orange lines). It can be difficult to remember the steps and rationale. Therefore, it is necessary for business users to go back to a certain history point to review, form another hypothesis and restart another analysis path.
- When a project requires multiple analysis sessions, which last for long periods of time the task can be interrupted or suspended. Reviewing the analytic provenance can help the business user faster and better resume the task.
- Provenance function can be also useful between collaboration and communication among colleagues. For example, an end user wants to explore an analytics reports made by a specialist. Then to understand what others have done is crucial. Therefore, the provenance function could help an end user to explain and explore other’s work.

Our user study findings reflect the problems that have been discussed in the usage of the analytic applications and in the literature review. And we focused on the user experience design for motivating users to recommit an interrupted or suspended task. Users are getting used to going back and forth among previous analysis steps to reinstate their reasoning process, as human

memory is limited and decays (Cowan, 2009), most of the time we cannot remember where we have left off, and how can I recommit the task And tracking the history becomes a barrier for exploration and commitment. Therefore, it is beneficial to design tools that help people recall their interaction history in a suspended and interrupted task, and to get a positive user experience.

## 4.4 EXPERIMENTAL METHOD

“When psychology seeks to verify the validity of an observation through an experiment, it becomes experimental psychology”<sup>10</sup>(Fraisse, 2005). Experiment is a significant phase in scientific research to test if a certain hypothesis is supported or refutable in a controlled condition. It is mainly based on hypothetico-deductive reasoning: we start from a theoretical hypothesis, infer consequences (predictions), and try to verify it (experimentally). Experimental methodology is for the researcher to vary an element or a variable of a situation to provoke a behavior (or to make it disappear) and to measure its evolution. It is usually to compare different conditions where the same task is conducted (experimental conditions vs. control condition). The participants are distributed randomly according to the different conditions, or the same participant does the same task in both conditions. Our goal is to study scientifically the influence of the determinant factors on users’ behavior and perception.

Our experimentation is conducted in the company, taking place in the real working environment rather than a laboratory. The advantage of a field experiment is that the results are observed in a natural setting, which is close to the real situation. However, compared to a laboratory experiment which is more controllable, a field experiment has more uncertain factors. So, the experimenters should take this uncertainty into account for analyzing the results.

### 4.4.1 MINIMALIST AS A FRAMEWORK FOR EXPERIMENT

The experimental method that is suitable for this work is minimalist experiment, which is employed in the CRED laboratory to study the perceptual phenomena mediated by tactile interfaces for the blind. It is about to reduce the sensory inputs to a minimum thus forcing a spatial and temporal deployment of perceptual activities (Lenay & Stewart, 2012). It is for reducing the complexity of a situation by neutralizing certain variables. In the experiment, we use an artefact consisting of the minimal features of human-environment or human-instrument coupling for the purpose of “simplifying to better understand” (Ammar, 2007).

There are two main advantages of minimalist experiment that we decide to use this method as a framework:

It is an experimental reduction. If the artifact in the experiment can make possible the most basic forms, then it will be easier to discover human and material characteristics (the actions, the exploratory strategies, the stimulus, the coupling) determining in the feasibility of the task. The

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<sup>10</sup> “Lorsque la psychologie cherche à vérifier la validité d'une observation à travers une expérience, elle devient psychologie expérimentale”

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minimalist method can be a principle for the design of perceptual interface, since the designer can concentrate on the possible type of action through the interface and the nature of perceptual experience that the system evokes from users.

The second advantage that we adopt the minimalism is for the reason of cost, transposability and ease of use from a technical point of view. In other words, we believe that the design for a particular perceptual experience in a minimalist situation (if the conditions are satisfied) could be applicable to another situation. Once the feasibility of the task is acquired, it remains to decide on the enrichment of the interface according to the specific needs.

## 4.5 CHAPTER SUMMARY

The research problem in terms of memory supplementation is formulated in this chapter based on the sensorimotor coupling positioned in the enactive approach. To verify if we are capable to answer this question and come out the design solution for testing, we follow the user-centered design process. We define the notion of BI and analytics, identify the intended users and understand its related process. We studied user model and previous user research studies in Business Intelligence (BI) and analytics domain. we discover that the theoretical problem coincides with the use case in the real working environment. This brings values to apply our research results to the real world. In order to better understand how people perceive the user interface, we construct an exploratory study to emerge the perception of interactive system from a professional perspective, that will be introduced in the next chapter. The insight that we discover from the user study and the exploratory study help us construct the design proposal for "in hand" mode history path which can be evaluated in the experiment.

To facilitate the evaluation of the design solutions, we decide to use the minimalist experiment as our experimental method, and we also introduce its advantages regarding to the feasibility of the task and the integration to other situations.



## CHAPTER 5 EXPERIMENT

*"No amount of experimentation can ever prove me right; a single experiment can prove me wrong."*

*— Albert Einstein, German physicist*

*"Users are not always logical, at least not on the surface. To be a great designer you need to look a little deeper into how people think and act."*

*— Paul Boag, UX designer and author*

C. Lenay et al.'s sensory-motor coupling and user study findings allow us to explore the emergence of emotional experience in the interactive systems. We consider that emotional experience emerges from the dynamics of user interaction and the perception of the system through this interaction. In the first place, we focus on the design of interactive applications, which provides users emotional experience. What are the characteristics for qualifying the interaction which lets emotions emerge? In the first part of this chapter, we first present a preliminary experiment to analyze the perception of interactive applications by experienced designers. In this experience, we are also interested in how people perceive the interface and interaction of the applications. In the second part of this chapter, we present the experimental environment based on a Tangram game that we have developed for evaluating the extent to which of a history path support can help the user for efficient recovering of an interrupted task. A tangram is a puzzle to construct a geometric shape using a set unitary geometric given shapes without overlapping each other. We used this game to simulate a problem-solving task and generalize our research problem.

### 5.1 EXPLORATORY STUDY

User experience designers are the final persons who must evaluate and validate the design of an application, consequently it is necessary to have a set of interaction vocabularies, which are common to their knowledge. Besides, they have already a good knowledge of user interface, user interaction principles, such as intuitive, consistent, aesthetics, etc. They can provide a set of standard semantic words expressing their experience of interaction such as perceived interaction characters. Therefore, we conducted a test to evaluate the user interface and interaction semantically referring to the sensory evaluation proposed by Lefebvre & Bassereau (2003). The objective of this test is to exploit the information to help evaluate the "in hand" mode interaction from a professional perspective.

## EXPERIMENT

First, we introduce the methodology that we used and the results that we could obtain from this test.

### 5.1.1 METHODOLOGY

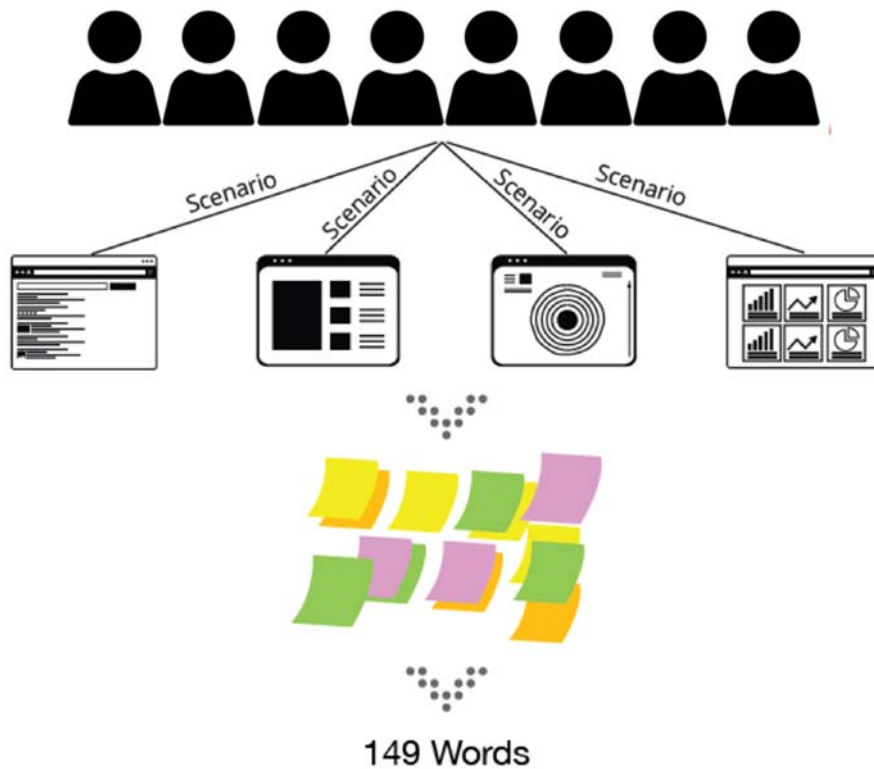


Figure 28. Exploratory study overview

#### 5.1.1.1 Participants

The experiment addressed 8 UX designers (4 females and 4 males) in the UX team of BI and analytics products in SAP. Their ages were between 23 and 49 years and they have years of varied experience in interaction design varied including cognitive science, ergonomics, service design and graphic design.

#### 5.1.1.2 Material

An introduction of the objective and the requirement is constructed in order to guide the participants ([appendix A.2.1](#)) and a questionnaire to set the profile was sent in advance by email for the participants to fill ([appendix A.2.2](#)) in advance including age, gender, preferred language, education background, work experience, frequently used applications.

During the test, a paper scenario of 4 different website applications are presented to the participants that they will have to follow. Four websites applications were selected among several online applications (see [Table 5](#), [Figure 29](#), and [appendix A.2.3](#)). They were chosen by

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virtue of their representativeness of different interactions which can evoke various evaluation criteria.

Table 5. Description of the 4 website applications

Name	Description
Google Image	A search service owned by Google that allows users to search the Web for image content.
Airbnb	An online marketplace and hospitality service, enabling people to lease or rent short-term lodging including vacation rentals, apartment rentals, homestays, hostel beds, or hotel rooms.
Zero Landfill	A website owned by Subaru which examines its own environmental history.
SmartBI	A search-based self-service business intelligence project in SAP.

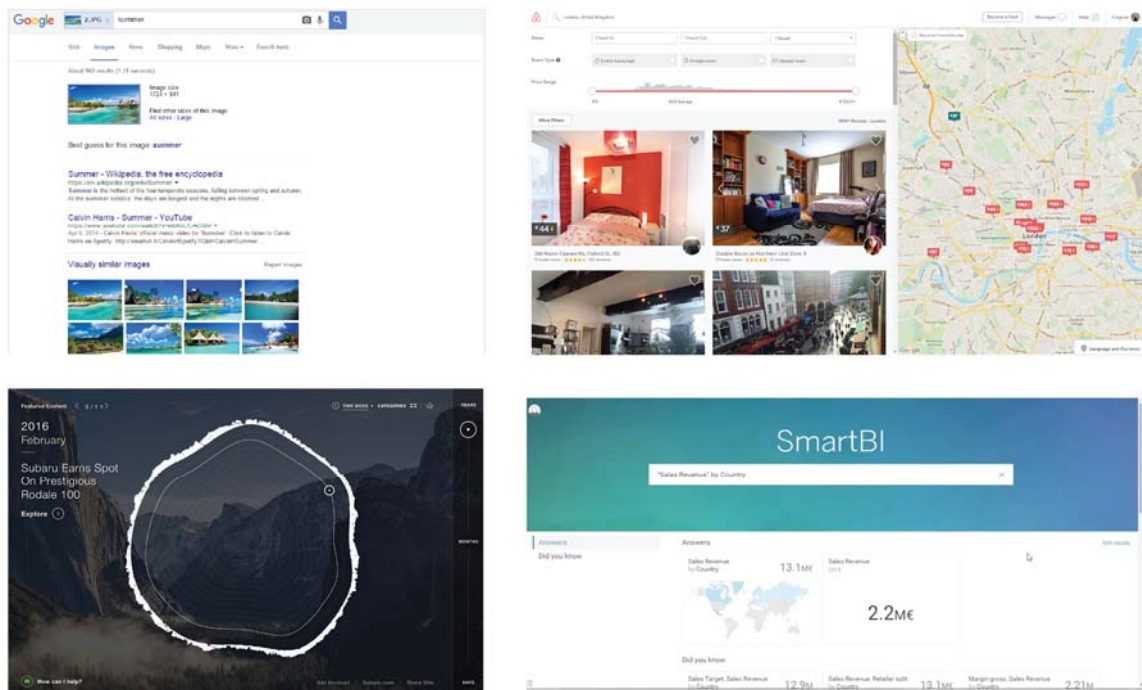


Figure 29. 4 selected website applications (Google Image: <https://www.google.com/imghp>; Airbnb: <https://www.airbnb.com/>; Zero Landfill: <http://www.subaru.com/csr/environment.html>; SmartBI: internal project.

### 5.1.1.3 Procedure

Before the evaluation, the participants were asked to write down descriptors to qualify the applications or websites that they frequently use for work and for daily life in the previous questionnaire. The objective was to have a word corpus for the following test. As required, the descriptor should be a qualitative adjective that can describe an interaction with the

## EXPERIMENT

application with respect of aesthetics, usability and hedonic quality. Before the test, the moderator gave a few examples of descriptors, and let the testers to think on their own.

Then, the participants were asked to follow 4 scenarios to interact with the 4 applications on their own laptop and to write the descriptors on the post-it notes that expressed their feeling about the extent to which the 4 interactive tools meet the interactive task requirements. Then, after one round, the post-it were stick on the wall.

### 5.1.2 RESULTS

We have collected 149 descriptors, which were freely proposed by the participants. We had then several steps for analyzing these descriptors.



Figure 30. Test overview - collected descriptors

1. *Preliminary Categorization based on our own interpretation.* Because the test exceeded 2 hours, we didn't have enough time to discuss immediately with the participants why they chose the descriptors and have an agreement with them. We made a preliminary categorization (See *Figure 31*), which resulted in 21 categories of descriptors.

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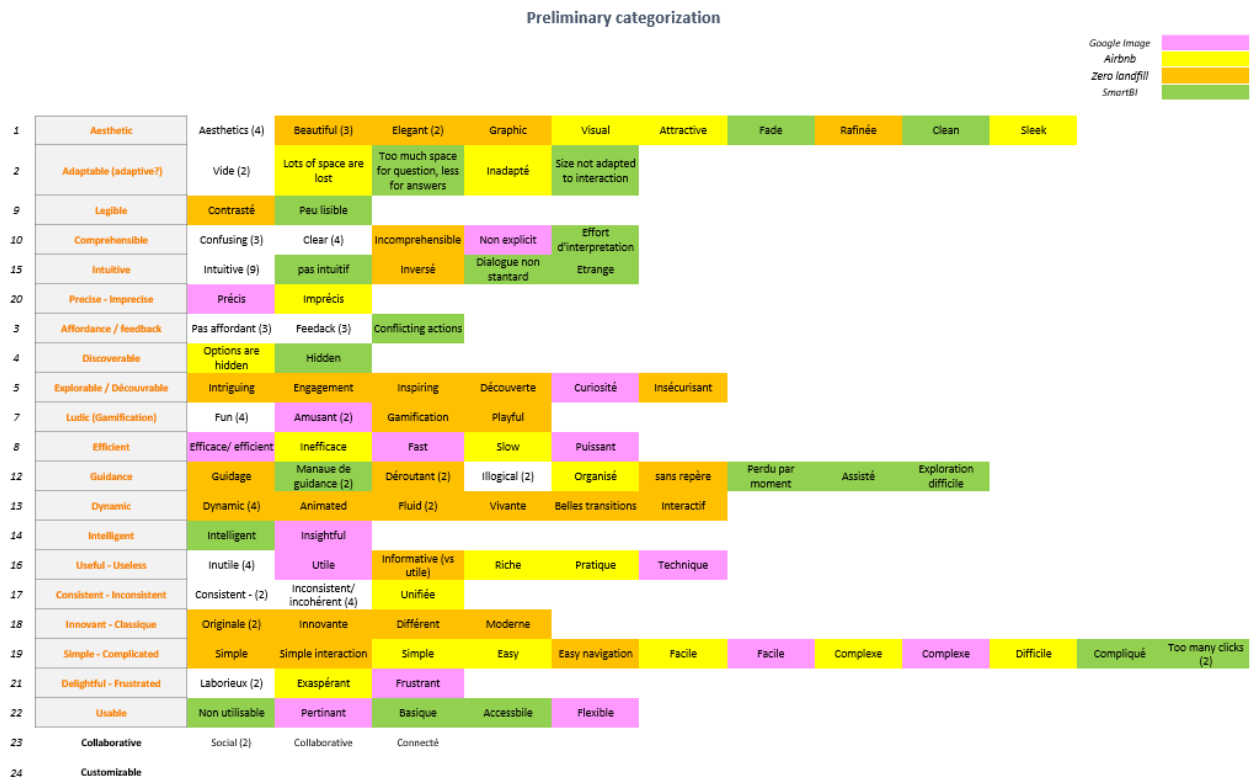


Figure 31. Preliminary categorization

2. *Secondary Categorization based on one to one interview asking for explanation.* We conducted a one to one interview sometime after the experiment to ask them to explain the reason of their choices of descriptors, each one for about 15 minutes. It resulted in 24 categories of descriptors. They are aesthetic, understandable, intuitive, guided, fun, easy, consistent, dynamic, useful, adaptable, fast, innovative, usable, engaging, standard, organized, effective, visible, intelligent, rich, accurate, legible, accessible and flexible.
3. *Description of each descriptors in terms of the usage of 4 applications.* Based on the explanation of the participants, we gave each category a description. This description was constructed on how they perceived the interaction with the four websites during the task. It is possible for different designers who gave the same descriptors but meant different things and who gave different descriptors but meant the same thing. For example, several people used "simple", one referred it to "simple to use", another referred it to "easy to understand". Then a correct description of each category is necessary.

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Figure 32. Final categorization after interviewing the participants

## 5.1.3 ANALYSIS

Based on the 24 categories, we then ranked the categories according to the total numbers of descriptor selection in each category for the four websites by the maximum numbers of descriptor selection. We selected the first 10 descriptors, which were the most often chosen by the designers to qualify the interaction qualities of the applications: understandable, aesthetic, Intuitive, fun, consistent, guided, adaptable, dynamic, easy and innovative (See Table 6).

Table 6. Ranking the categories

Descriptors	Number of selections		Max	
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	(Expert 1 to 8)				Total number of selections	4 apps * 8 experts	Mean (number of selections/Max)
	App1	App2	App3	App4			
Understandable	3	7	2	4	16	32	0,500
Aesthetic	0	4	5	3	12	32	0,375
Intuitive	3	3	3	3	12	32	0,375
Fun	3	1	3	2	9	32	0,281
Consistent	3	1	1	3	8	32	0,250
Guided	1	1	3	3	8	32	0,250
Adaptable	0	2	1	3	6	32	0,188
Dynamic	0	0	6	0	6	32	0,188
Easy	1	3	1	1	6	32	0,188
Innovative	0	0	5	1	6	32	0,188
Fast	3	2	0	0	5	32	0,156
Usable	2	1	0	1	4	32	0,125
Useful	1	1	1	1	4	32	0,125
Engaging	1	0	3	0	4	32	0,125
Effective	2	1	0	0	3	32	0,094
Visible	0	1	0	2	3	32	0,094
Organized	0	1	0	1	2	32	0,063
Intelligent	1	0	0	1	2	32	0,063
Rich	0	1	0	1	2	32	0,063
Standard	0	0	1	1	2	32	0,063
Accurate	1	0	0	0	1	32	0,031
Legible	0	0	1	0	1	32	0,031
Accessible	0	0	0	1	1	32	0,031
Flexible	1	0	0	0	1	32	0,031
					124	768	0,161

Global Mean = Total of times / Total of observations = 0,161

We then recheck of the 149 descriptors with the comments of the experts, from which we picked the categories in which the 8 experts used the emotional qualificatives to express their feeling towards the 4 applications. In Table 7, we listed the categories of these descriptors, the qualifiers the experts used in the test, and the explanations which explain the meaning of the words. (Wanru, 2015) proposed an experience EPI model and argued that an experience is composed of expectation, progression and influence. We found that the cause of these emotional qualifiers was related to these three elements, so we adapted

## EXPERIMENT

this model to the HCI context and concluded into three types of cause: expectation, interaction and impact.

Table 7. Emotional descriptors and their connotation

Category	Word	Explanation	Connotation
Understandable	confusing, attempt to interpret	Mapping between action and feedback	Interaction – cognitive load
Aesthetic	attractive, elegant, fade	Graphic/Visual	Expectation – first impression
Intuitive	insecure, confusing	Uncertainty, not sure about what will happen once the action is done.	Interaction – habit
Fun	amusing, fun, playful	Appeal to the activity	Impact
Consistent <sup>11</sup>		Consistence between the action and the result or response (feedback)	Interaction
Guided	disturbing	Lose the context	Interaction – positioning
Adaptable	empty	Whether the interface is adaptive to the screen size.	Interaction - layout
Dynamic	living	The fluidity, animation and movement	Interaction – feedback
Easy	annoying, laborious	The difficulty to finish an action	Interaction – feedback
Innovative	original, basic, modern	New way of interaction which is unknown or different from others, very original, otherwise, rudimentary interaction.	Expectation – Habit
Fast	Immediate feedback	Emphasis on the speed	Interaction – feedback
Engaging	curious, intriguing	Want to know what will happen next	Impact
Usable	frustrating	Cannot satisfy the user's needs	Expectation – needs

1. *Expectation*: expectation refers to the act of anticipating before or during the interaction with an object according to one's past experience and needs. No matter a good or bad result depends on what we expected at the very beginning. For example, *Aesthetic* using attractive, elegant and bland expressed their first impression of the applications. *Usable* qualified by frustrating suggested that the function of certain application failed to meet the expert's needs.
2. *Interaction*: during this task, anything related to the interaction between the user and the system. What kind of expectation the user has can lead to different interactions? For example, the experts mentioned *understandable* using confusing and effort to interpret to express the mapping between action taken and feedback. In the test, the experts took an action, while the feedback did not reach their expectation, so they felt confused. Another example, *fast*, the experts described that they obtained an immediate feedback after undertaking an action, which met their expectation, and so their experience was improved.

<sup>11</sup> Note that "consistent" were not expressed by the experts using emotional words, however it was ranked relatively high, we will take it into account.



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3. *Impact*: after the interaction with the system, what kind of feeling the user can have in relate to this task. The strength of the interaction determines the profoundness of the impact. *Fun* means that the experts found the applications was rewarding and enjoyable. *Engaging*, the experts want to know what will happen.

#### 5.1.4 CONCLUSION OF THE EXPLORATORY STUDY

In this section, we have presented the first test that we have experienced with design experts to define a framework for defining a set of qualifiers for interactive applications. We defined a scenario that the experts should follow to express their feelings about the extent to which the 4 interactive tools meet interactive task requirements. From this, we collected 149 qualifiers, which were freely proposed by the expert designers, and classified them into 24 categories such as aesthetics, understandable, intuitive, fun, etc. Then, we analyzed these categories to exhibit the characteristics that were most frequently used and shared by the expert designers to evaluate the interaction qualities of the applications. In addition, we selected the emotional qualifiers used by the experts and then divided them into different causes – expectation, interaction and impact. This gives us insights to define a questionnaire scope for the experiment and classes of criteria that can be used to design an application from which the users can perceive the emotional effects.

This study helps us construct a vocabulary of evaluation of the design for “in hand” mode history tool and to conduct the Tangram experiment to measure positive experience, which we will transform into a model for the design interactive BI applications.

As presented in the introduction of this chapter, we built an experimental environment for evaluating the extent to which a history path support can help the user for efficient recovering of an interrupted task. We used this game to simulate a problem-solving task and generalize our research problem. In our tangram game, the history path (HP) plays the role of a provenance function. We explored users’ behaviors and their eye movements along their use of the history path. The analysis of the data collected during a first experiment, let us find that the users had different and personal strategies of using the history path, considered as in a “put down” mode in this case. This gave us an insight to rethink about designing an “in hand” history path mode, which would allow users to go back to the interaction history to explore the dynamic of their previous attempts of resolution. We hypothesize that the “in hand” mode of interaction history, which would allow a natural coupling between a user’s action and the provenance function, may lead to a positive user experience. A second Tangram experiment was then conducted to verify this hypothesis and draw a conclusion about how to apply this framework in SAP BI and analytic applications.

# 5.2 FIRST TANGRAM EXPERIMENT - EXPLORE THE DESIGN SPACE

## 5.2.1 METHODOLOGY

### 5.2.1.1 Participants

18 valid participants were invited in the test, there were no constraints on the participants' profile. Most of the participants were employees in the company between 25 and 54 years old. The test is composed of two parts: pre-test and test with the same group of participants.

### 5.2.1.2 Material

We developed a web-based prototype based on the Tangram game. The experimental protocol was set in two phases. Firstly, a simple Tangram game was used in a *pre-test*, the aim of which was to collect data and information recorded in the form of a video of the participants' interaction activities to resolve the task. Secondly, the same Tangram game, using the same prototype but with the addition of a provenance function corresponding to the video representing the history path to help the participants to resolve the task.

We provided a laptop for all the participants with the Tangram game prototype. We also used a Tobii X2-30 eye tracker to track users' eye movement in order to observe their behavior in relation to their eye movement on the history path area.

A questionnaire about their profile was asked to fill by the participants after the test (Appendix).

### 5.2.1.3 Procedure and tasks

The test consisted of a pre-test and a test. The pre-test was for collecting the interaction history that was used in the test. A Tobii eye tracker X2-30 was installed on the laptop to detect the participants' eye movements between the history path window and the tangram game window. The two sessions recorded the eye movements, screen, video and audio. Note that in this experiment, we were not interested whether the participants succeeded in resolving the task, but how they possibly adapted their strategies during the problem-solving process.

*Pre-test:* the participants were introduced to the test objective and confidential issues. Before the formal test, they were given around 1 minute to be familiar with the prototype, and then we calibrated the eye tracker. After all setup, participants were given 10 minutes to try to resolve the problem (See *Figure 33*: pre-test). They were also asked to fill a questionnaire for their profile. Finally, we asked the participants not to search for the solution in anyway until the next test.

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*Test:* 7 or 10 days later, we invited the same participants to play the Tangram game again. A history path of the videos in chronological order, which captured their past actions in the pre-test was available (see *Figure 33: test*) was available. Each video was chosen based on their attempts to compose a kind of basic shape (which we name “a composition”), which lasts for around ten seconds. Each video was displayed in the “pause” mode at the last frame, which means that the participants could see the last frame of the video at the beginning of test, and they could click on the button to play the video.

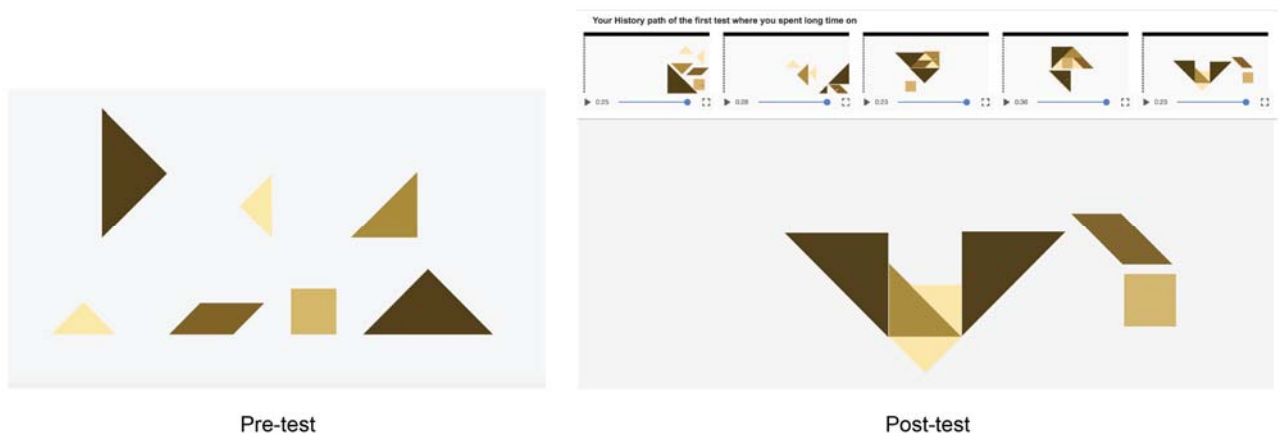


Figure 33. Tangram games in pre-test, and test with history path

## 5.2.2 RESULTS

We first analyzed the eye gaze video in the post test and normalized the way in which they interacted with the history path (HP) in three categories: simply scan the HP as a static image (they glanced at the thumbnail of the video without playing it), replay the HP (they clicked on the play button to scrutinize what they had done) and NA (no action to the HP). We did the same with what they did after the interaction with the HP in two categories: they repeated the composition in the HP or they avoided the composition in the HP). The X-axis in *Figure 34* represents the number of participants; the blue, the orange, the gray and the yellow bars represent respectively the number of participants who avoided to rebuild the same compositions as in the pre-test, those who repeated the same compositions, those who first repeated then avoid doing the same compositions and those who first avoided after looking at HP then repeated it without seeing HP.

## EXPERIMENT

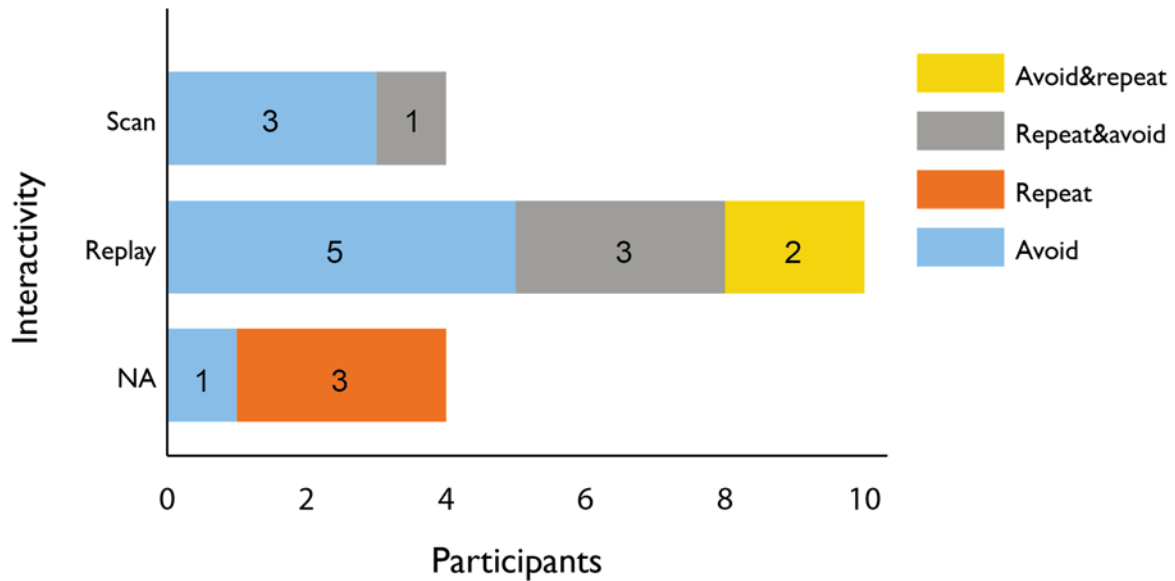


Figure 34. Number of participants' reaction to their interactivity to the HP during the Post test

As shown the figure above, there were 4 participants who didn't look at the HP during the test (NA):

- 3 of these 4 participants have repeated the compositions that they already did in the pre-test, although if they didn't look at it.
- Only one of these 4 participants tried to avoid doing the same composition as that she did in the pre-test. In fact, this participant had already succeeded to resolve the task during the pre-test in 2 minutes. Since there were two possible solutions to build the tangram, we asked her to find another solution. So, she tried purposely to avoid repeating what she had successfully done in the pre-test.

There was a total of 14 participants who have looked at the HP during the test (scan and replay):

- 10 of them replayed the video, 5 of them avoided doing the same composition, 3 of them first repeated the composition and then avoided doing the same ones, and 2 of them firstly avoided doing the same composition as that they saw in the HP, then they repeated the compositions without looking at the HP.
- 4 of the 14 participants have just scanned it, 3 of them avoided doing the same composition as that they did in the pre-test, and one repeated some compositions seen in the HP, then avoided doing the same ones.

The gaze plot detected by the eye tracker (See Figure 35) shows that the participants who replayed the compositions of the HP spent more time than the other who just scanned it for looking at the content in the video (See Figure 35: A) than the participant who just scanned it (See Figure 35: B). This is indicated by their number of fixations and the duration of fixations. This gave us an insight of the correspondence between the eyes movements and an aid for measuring the commitment in the interaction.

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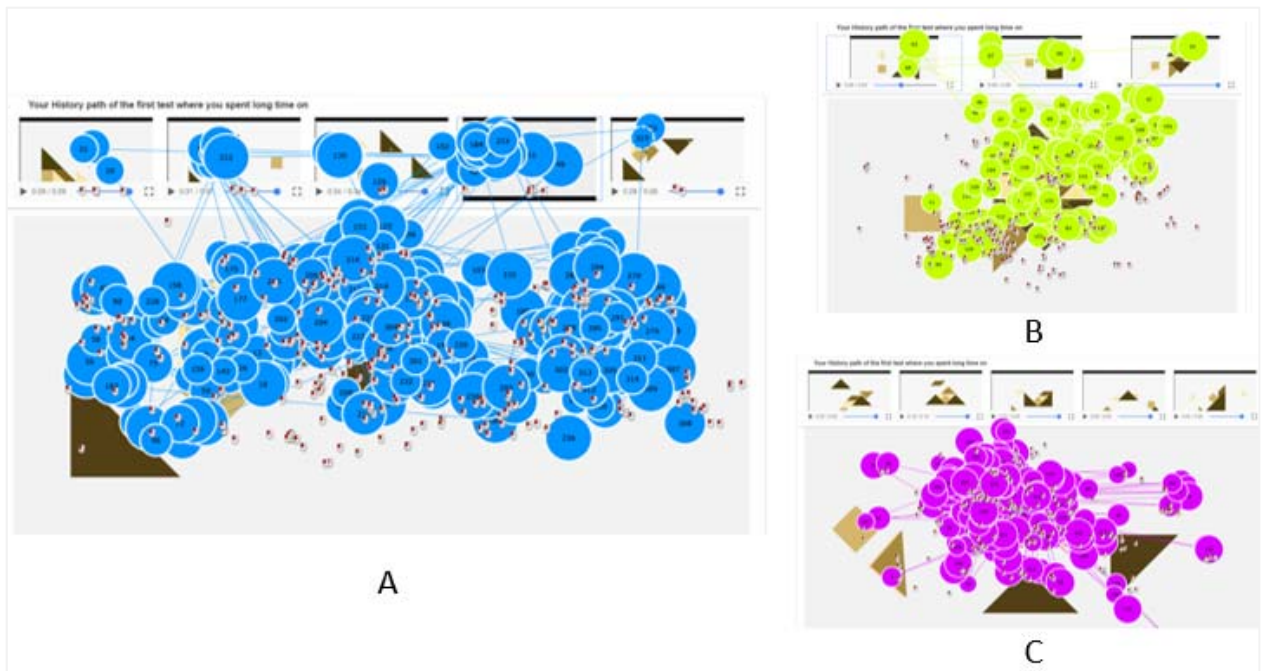


Figure 35. Example of the gaze plot: A. replayed HP; B. scanned HP; C. No action on HP (NA)

The data we used are fixation count that is how many times the participants have fixed on the HP area and the fixation duration that refers to how long they have fixed on the HP area. As we can see in Table 8, the average of the fixation count in the history path in *replay* (28,20 s) is more than twice the one in *scan* (12,75 s). The average of total fixation duration in the history path in *replay* (42,26 s) is four times longer than the one in *scan* (10,94 s). This gave us an insight of the correspondence between the eyes movements and an aid for measuring the commitment in the interaction.

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Table 8. Gaze data for participants who played (top) and who scanned the HP (bottom)

Participants (replay)	Fixation Count	Fixation Duration Mean (seconds)	Fixation Duration (seconds)
P20	15	3,71	55,72
P33	10	2,72	27,2
P34	33	0,88	29,17
P36	24	2,01	48,33
P42	54	0,88	47,59
P46	47	1,52	71,28
P49	40	1,54	61,42
P51	16	1,75	28,02
P52	23	0,96	22,17
P54	20	1,58	31,68
<b>Mean</b>	<b>28,20</b>	<b>1,76</b>	<b>42,26</b>

Participants (scan)	Fixation Count	Fixation Duration Mean (seconds)	Fixation Duration (seconds)
P28	29	3,71	28,51
P31	1	2,72	1,21
P37	10	0,88	9,28
P45	11	0,43	4,76
<b>Mean</b>	<b>12,75</b>	<b>1,94</b>	<b>10,94</b>

### 5.2.3 DISCUSSION

We can observe that displaying the HP constitutes a sign that involves the participants. Effectively, as 10 out of 18 replayed their previous compositions, 4 just scanned them, and only 4 did not look at the HP. However, despite 14 out of 18 looked at the HP, the HP considered as a coupling device is not involving enough to allow participants to grasp their previous strategy and to build a new one based on these considerations. In addition, although we are mainly interested in their strategies to solve the problem rather than the success of the task, from the post questions, the success or failure did influence their impression on the HP.

Combining these comments with the answers of the participants to the post questions, we discuss the reasons why they have different behaviors hereunder.

*Avoid*: as stated by the participants, their failure in the pre-test make them think that what they did was useless, and consequently that the history path served as a reference both to avoid the same composition and to verify if their new composition had not been already done in the pre-test.

*Repeat then avoid*: as observed from their gaze replay, they first found the video in the history path most interesting or matching their ideas, and then repeated the same compositions. After several attempts, they didn't find it helpful, then they tried to avoid it for the remaining part of the test (for the same reasons as *avoid*).

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Note that there was one participant who repeated the same composition found in the HP without seeing it at first. We considered that this participant belongs to the group of the participants who did not see the History path.

*Avoid then repeat:* the same reasons for avoiding that looked at the HP to avoid the same compositions and to verify if their new composition had not been already done in the pre-test. As they still did not find the solution, then they gave up looking at the HP. However, one interesting thing was that they began to repeat the composition as they had done in the pre-test when they stopped looking at the HP. Therefore, we considered that they belong to the group of the participants who did not see the History path.

For the participants who did not look at the history path, 3 out of 4 participants tended to repeat what they did in the pre-test unconsciously, even if they thought the HP was useless because they didn't succeed the first time. This is also the reason why they didn't want to look at the history path. This repetition is probably because that they were unaware that they had done it in the pre-test. As such, with the HP, if they found an interesting composition, they could reuse it, otherwise, they could avoid repeating the same errors. In the former case, if they had looked at the history path, they would have rapidly finished some composition and check if it was right. In the latter case, they could avoid the same errors and explore the new solution. Therefore, in both cases, they could improve their efficiency.

However, as said by most of these participants, to look at the history path is a waste of time and could be also a distraction, which could slow their process, given that they had 10 minutes to finish the task. They also stated that if in the pre-test, they felt close to the answer, they would have looked at the history path.

Above all, the participants tried to avoid consciously or repeat unconsciously the same attempts they had done in the pre-test. The avoidance behavior indicates that the HP serves as a support for their reasoning process. In addition, when the participants played the video, to some extent, they were engaged in the action-feedback loop. As shown in the eye movement of Fig. 3 and Table 1, people focused longer in the video when they played than when they just scanned the static image. We can infer that a direct coupling between action and function is realized by this kind of demonstration. However, it is not a direct coupling between the user's current task and the HP. Besides, the participants had to work a lot to understand what they had done before and compare it with what they were doing now. In this case, the HP is still in the "put down" mode, which did not help enough the user to get a perception of the world they built and to get a positive user experience.

Let's hypothesize now that the "in hand" mode of the HP will allow a natural coupling with user action and that the use of a provenance function may lead to a positive user experience. In the next step, we will focus on the design of the history path in the "in hand" mode. It is aimed at making users aware of their successive attempts for exploring other possibilities, and thus improving the task performance consequently.

## 5.3 DESIGNING FOR “IN HAND” MODE HISTORY PATH

The history path serves as a support for problem-solving, however, in the previous experience, the HP was still in the “put down” mode, which did not help enough the user to get a perception of the world they built and to get a positive user experience. Observing from the participants’ behavior, we found common patterns among their interaction history. This gave us an insight to rethink about the design of the “in hand” history path so as to allow users to go back to the interaction history to explore the dynamic of their previous attempts of resolution.

In order to design a dynamic HP in the “in hand” mode, we consider its visual representation as well as the accompanied interaction. In this section, we propose a design direction that we are going to implement in the next experiment to verify the hypothesis.

### 5.3.1 THE SELECTION OF HISTORY PATH

As we mentioned in the previous section, the “in hand” mode of history path can give users an insight from “what has been done” to “how did I get here?” and “what should I do next?”. As a result, the history path may be beneficial for exploration. For example, when the users do an action, the history path visualization reveals important information correspondingly, encouraging more insightful exploration leading to the solution.

From the first Tangram experiment, we observed that each participant had his or her own strategy for solving the problem (See *Figure 36*). For example, some started from the big triangle, some from the square, some started from visioning the top of a triangle, etc. However, the experiment struggled to reinstate their previous reasoning process just by presenting the history path chronologically. The resulting questions was linked to how we define the history in Lenay et al.’s model of interaction. We propose to design the HP as more involving, through its continuous enrichment along the task. We consider encoding users’ strategy by computing their interaction history using certain data. We aim at identifying the patterns that we can display in order to assist users in overcoming their deadlock and conducting another exploration.



Figure 36. Example of strategies of three participants

In the first Tangram experiment, we used the 7 shapes. As indicated by the participants, the game was difficult for them to find the solution within 10 minutes. Therefore, we reduced the number of shapes from 7 to 5 in order to lower the difficulty of the task.



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Users started from 2 shapes and added other shapes one by one to construct a form which they think is close to the triangle. The forms of intermediate steps which consisted of at least two shapes are called a *composition*. Until they realized that the final form was not the solution, they decomposed the form, and iterated the previous steps until they found the solution.

During this process, it was very common that they built the same composition after a while, and then repeated the same steps unconsciously. Therefore, we computed the position of the components of a composition to obtain a dynamic trace of how the components were linked (by edges, vertices, ...) and how some were added or removed. We record users' attempts of composition, and displayed similar previous attempts found in the HP, dynamically based on the user's current action. We marked the composition with two shapes as the starting point of each path and eliminated the same compositions during the task resolution. Finally, the remaining compositions of all the previous attempts are presented according to their similarity and the previous steps as the history path.

### 5.3.2 THE REPRESENTATION OF HISTORY PATH

We choose to represent the history path in the form of a tree-like diagram, where each branch starts from a composition of at least two shapes. The tree-like diagram can be clearly perceived by users to understand the construction path they did before (how did I get there?). For example, a triangle with a diamond altogether is a composition, which can be seen as the root of the tree. When the user adds a square, the system displays this composition as part of this branch. However, when the user removes the square and replaces it with a triangle or changes its orientation, then another composition is created, enriching the history path by a common core and several branches (See *Figure 37*).

The global arrangement of the history path is presented in two dimensions, in a display of X-Y coordinate:

**The X-axis:** a branch starts with a composition. The distance between the branches are based on their similarity. for example, a triangle and a diamond. The composition with the same shapes but different orientation is closer than composition with different shapes.

**The Y-axis:** the number of shapes in a composition (from 2-5).

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Figure 37. Example of history path representation (static history path)

From the interaction of dynamic history path point of view, by default, all the paths are semi-transparent. When the user is setting a composition in the workspace, the branch, which corresponds to the current action will be highlighted, otherwise, the branch will remain semi-transparent (See Figure 38). The branch, which consists of the exact user's current action will be displayed in color (orange). In this way, users can experience each exploration reflected from the HP's branch. The resulting HP coupling device allows to build new actions based on the perception of the results of their exploration and the proximity of previous exploration.

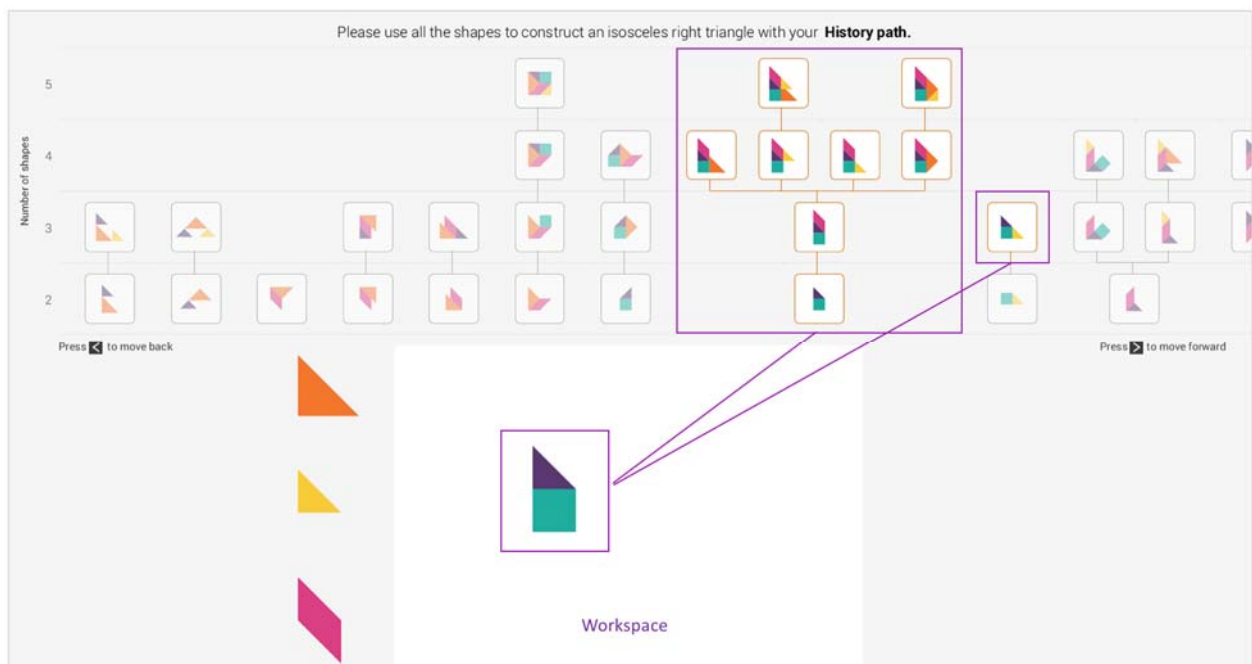


Figure 38. Illustration of dynamics of history path (dynamic history path)

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Note that, ideally, we would like to present all the possible path corresponding to the user's current composition. For example, in Figure 38, the highlight path is the square plus a purple triangle. In this game, the purple triangle is the same as the yellow triangle (right to the highlight in Figure 38.). Then the composition of a square and a yellow triangle should be highlighted as well. And if the entire composition rotates (e.g.  $45^\circ$ ), which is in the history path, it should be highlighted as well. However, we did not realize this function due to technique limitation.

Another proposition is to display the complete static history path of the previous experience, with no interaction during the task resolution (See Figure 39)

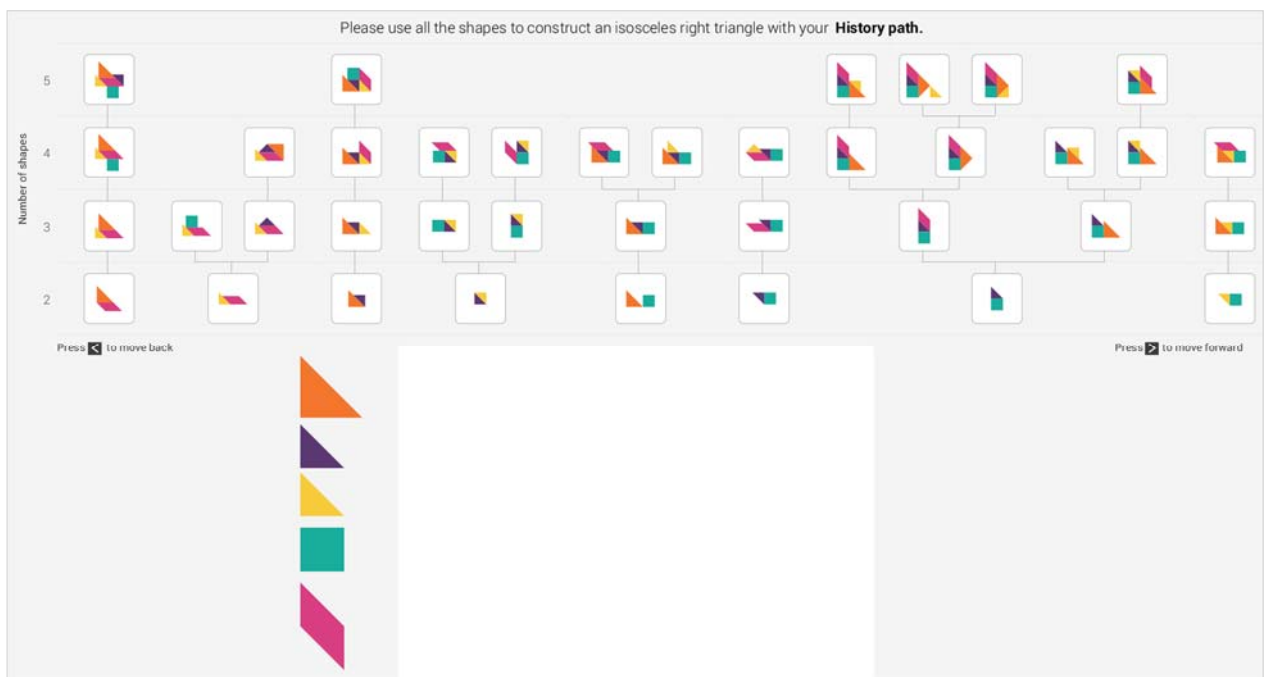


Figure 39. Illustration of static history path

Based on these two new design proposals, we conducted our second Tangram experiment, the objective of which is to verify if dynamic history path or a static history path can help users for solving tasks and discover new exploration. Based on these works, we introduce our evaluation protocol and then we present the experiment afterwards.

In the next section, we examine if the design for "in hand" mode history path will allow a natural coupling with user action and if the use of provenance function leads to a positive experience. We use "dynamic" to represent the "in hand" mode history path and "static" as a control group.

In terms of natural coupling with user action, we considered that the use of history path can help users explore other possibilities of attempts and develop ideas so that they succeed in the task resolution. There is also a relation between eye tracking measures and the cognitive process: the more saccades in an area of interest (AOI), the more searching is intense. The number of fixations and fixation durations can also be a measure for task performance and attractiveness, according to Bojko's (2013) work.

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In terms of positive experience, we used subjective measures that we obtained from the [Exploratory study](#) (presented in the previous section) to evaluate the user's perception of interaction with the history path. We also conducted qualitative analysis on participants' retrospective think aloud (RTA) verbalization to evaluate their lived experience during the *task resolution* phase.

### 5.4 SECOND TANGRAM EXPERIMENT - DESIGNING FOR "IN HAND" MODE

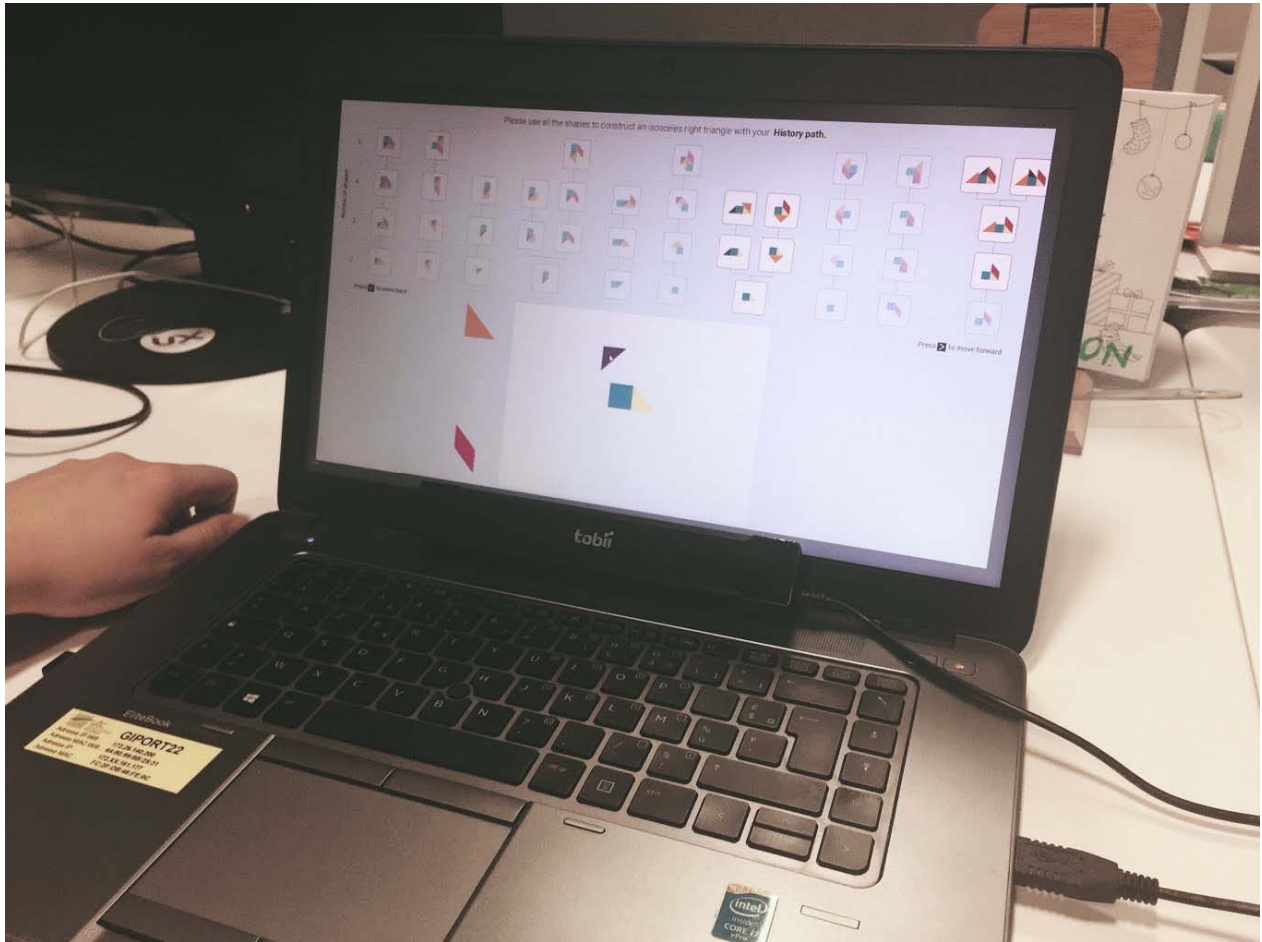


Figure 40. Second Tangram experiment

The second experiment is to verify if a dynamic history path compared with a static history path can help its users with their problem-solving tasks and discover new reflection avenues. Based on these works, we introduce our evaluation protocol and then we present the corresponding experiment.

## 5.4.1 METHODOLOGY

### 5.4.1.1 Participants

We have recruited 34 new participants who volunteered to participate our experiment. As well as in the first experiment, there were no constrains for the participants' profile. Most of the participants were employees in the company, and between 25 and 54 years old. The test was composed of two parts: pre-test and test with the same group of participants.

### 5.4.1.2 Material

We integrated the new design into the prototype as a java application. The prototype was installed on a specific laptop for the experiment. We also used the Tobii X2-30 eye tracker to track users' eye movement in order to observe their behavior in relation to their eye movement on the history path area. The screen recording software was installed on the laptop. The experimenter used a pen and paper to write down notes during the test. The whole session is recorded for screen, eye tracking, users' voices.

All the participants had to fill the online [user profile questionnaire](#) and [an evaluation questionnaire](#) is available for every participant.

### 5.4.1.3 Procedure and tasks

The experiment has two sessions in the same way as in the first experiment: pre-test and test.

#### *Pre-test*

Before the task, the test objective was shortly introduced to each participant. The procedure was first explained shortly, and the participants were told that they could quit the test at any time. They were then introduced on how to play the game shortly. A maximum of 2 minutes was given for practice on the application. All participants were allowed to ask any questions related to the experiment before the formal test.

They were allowed to begin at any time when they felt ready. All participants were asked to solve the same tangram puzzle with the same user interface within 10 minutes (SFigure 41). The participants were told that the objective of this research is to understand the software usage and to verify if the concept facilitates problem-solving tasks. After the test, the participants were asked to fill in an [online demographic survey](#) about some personal information (sex, age, educational background, ...). All participants were asked not to search the answer by any means and they were informed that they will have to do the same task two weeks later.

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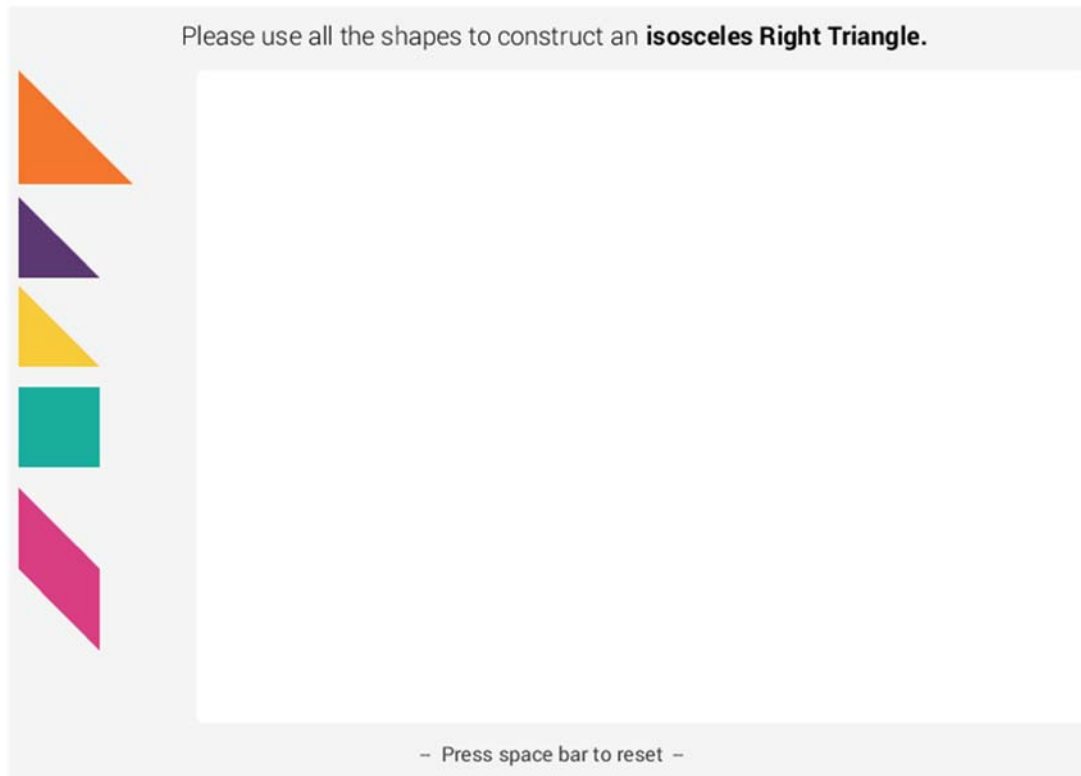


Figure 41. Screenshot of second Tangram experiment: pre-test

The objective of the pre-test is to obtain the participants' usage path data in order to construct the history path which is presented in the test.

### *Test*

10 days later, the same participants were invited to the test. We conducted a between-subject experiment. Based on the number of the participants who succeeded in the pre-test and those who did not and their profile, we divided them into two groups. The first group will use the static history path presented in the previous section and the second group will use the dynamic history path. All the participants were informed that their eye movements and voice will be recorded.

Participants were calibrated using a standard 9-point calibration (according to Tobii Technology, 2011) where the point was set to move between the positions at a slightly higher speed than normal. The calibration points were red dots with a central black dot shown on a neutral gray background. An automated calibration procedure was used, which was initiated by the moderator.

The procedure consisted of four phases: *instruction, task resolution and post questionnaire and gaze video cued retrospective thinking aloud (RTA)*. It took about 1 hour per participant.

In the *instruction* phase, we prepared an example respectively for dynamic and static history path recorded from other people than the participants themselves. With the example, we first introduced the history path concept and how to interact with the application to the participants. Then we provided participants with an instruction page that briefly described their task as below:

"Thank you for participating the Tangram experiment.

In the next page, you will try to solve the Tangram game as you did last time to compose an isosceles right triangle using all the five shapes without overlaying within 15 min. You can refer to your history path during the test.

After that, you will be asked to fill a questionnaire, and to rate your perception of the history path function.

"When you are ready, please click on a number of the screen to start."

During the *task resolution* phase, the participants were left alone in the room to complete the task, we tried not to interfere with them during the experiment. We set the timer for **15 minutes** when they were ready, and we left the room. Because there was a new function in the test, we increased the time to 15 minutes for taking the use of this new function into account. If the participants succeeded within 15 minutes, the test was stopped, and the experimenter entered the room. otherwise, the task was interrupted by the experimenter. The task was ended.

After completing the task, the *post questionnaire* phase began by answering a questionnaire survey consisted of 8 items measuring their perception of the history path function. The 8 items are a pair of opposite adjectives, which were the most frequently used and shared by expert designers to evaluate the interaction qualities of interactive applications the that we obtained from the [exploratory study](#). They are understandable – confusing, intuitive – non-intuitive, boring – amusing, consistent – inconsistent, misleading – guiding, useful – useless, pleasant – unpleasant, original – classical. The questionnaire was provided to the participants as an [online survey form](#). We switched the order of each pair of words which was different from the previous one in order to avoid the participants to thinking too much about their answers (just check mostly one side or the other). The answers could take one value among a five-point Likert-type scale from 1 to 5 (See Figure 42). For example, in the case of understandable – confusing, a rate 1 means that the participant evaluates the history path function as very understandable; a rate 5 means that it is very confusing.

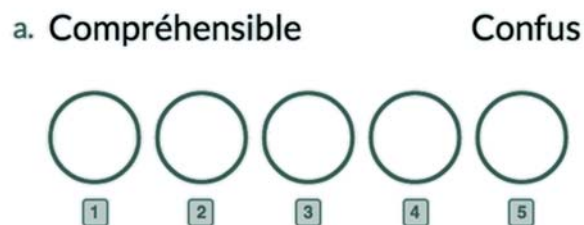


Figure 42. Online survey screenshot

In the *gaze video cued RTA* phase, participants were shown the video recorded with their eye movement. They were asked to comment aloud the task they just completed. They could fast forward, rewind or pause the video if they wanted and could also use the mouse to point at things on the screen during the interview. The video was shown by default at half

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the speed from the start of the RTA interview, for about 30 minutes. The participant's reactions and comments about the task they just completed were screen and audio recorded.

During the RTA interview, we tried to let the participants talk more about their thoughts, and we sometimes asked them some questions like "I see you're looking at ... (history path, the shapes, etc.), what were you thinking about when you looked at it?".

Regarding the evaluation method, we use both subjective and objective measures. Subjective measures are based on the semantic analysis such as developed by Osgood, Suci, & Tannenbaum (1957) to evaluate the subjective impression on the HP. The participants were asked about their perception about the interaction quality based on a set of adjective descriptors that we obtained from a previous study (Yang, Morizet-mahoudeaux, Guénand, & Mouloudi, 2016). For objective measures, we included the eye tracking metrics, the time spent to resolve the task, the numbers of success. A comparison analysis between the static and dynamic history was carried out to test the hypothesis. We gathered the results to analyze users' commitment during this second experiment and compare it to the previous experiment.

### 5.4.2 RESULTS

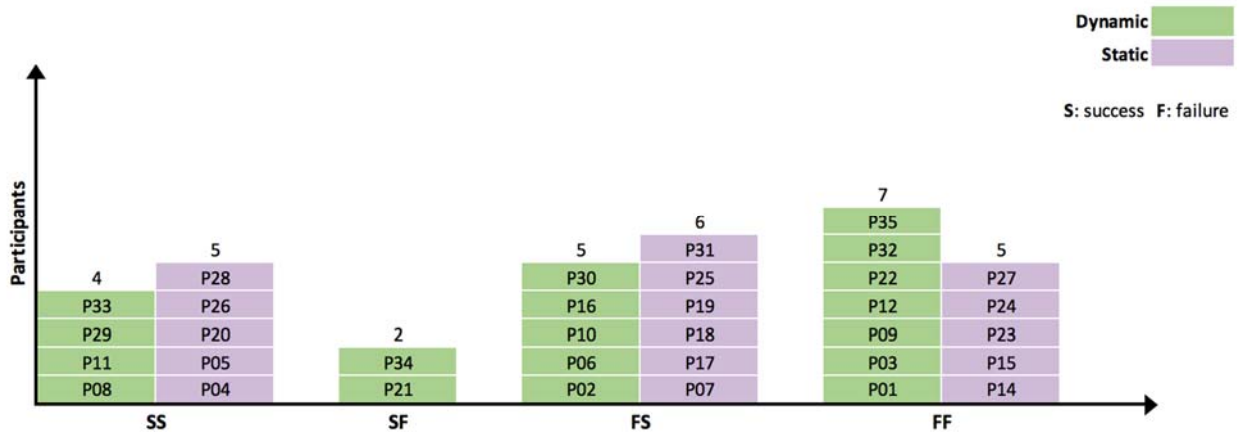
Among the 34 participants, there are 11 participants who succeeded in the pre-test within 10 minutes and 23 participants who failed. In the test, 18 participants were divided into dynamic history path (HP) group, and 16 participants were divided into the static HP group. Totally, there were 20 participants who succeeded in the test within 15 minutes, 9 of whom with dynamic HP and 11 of whom with static HP. There were 14 participants who failed in the test, 9 of whom with dynamic HP and 5 of whom with static HP. We then categorized them into 7 groups and 3 stages (the beginning, on-going and the end) of using the HP during task resolution for analysis:

- **SS (D)** – the participants who succeeded both in the pre-test and the test with the dynamic HP.
- **SS (S)** – the participants who succeeded both in the pre-test and the test with the static HP.
- **SF (D)** – the participants who succeeded in the pre-test and failed in the test (only the participants with the dynamic HP).
- **FS (D)** – the participants who failed in the pre-test and succeeded in the test with the dynamic HP.
- **FS (S)** – the participants who failed in the pre-test and succeeded in the test with the static HP.
- **FF (D)** – the participants who failed both in the pre-test and the test with the dynamic HP.
- **FF (S)** – the participants who failed both in the pre-test and the test with the static HP.



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From the *Figure 43*, we can see that that there were four SS (D) compared to five SS (S), two SF (D), five FS (D) compared to six FS (S), and seven FF (D) compared to five FF (S).



*Figure 43. Distribution of participants who succeeded or failed in the pre-test and the test*

As all the five SS (S) and one participant (P33) among SS (D) who succeeded in the game within 2 min, they did not use the history path for problem-solving. As the puzzle was easy for them, it did not overtax their working memory so that they did not need the history path for the memory recall. Therefore, we can infer that if the task is too easy for the users, they will not need the history path for the task resolution. There was one participant (P08) with SS (D) who misunderstood the task, as she thought that the number of shapes had been changed in the test which was different from the pre-test. She did not use the history path in the right way. Therefore, we did not analyze these 7 participants.

With this output on the success vs. fail and static vs. dynamic, we analyzed the results from three kinds of measures: eye tracking data, RTA verbalization and semantic evaluation that are presented in the following parts.

#### 5.4.2.1 Eye tracking data

What we are interested is how people use the history, for how long did they fix on the HP area and how many saccades they did in the HP area. We first draw an area of interest for the HP area (See *Figure 44*). And then we extracted the eye tracking data (fixation duration and number of saccades) in the HP area of interest (AOI) from the eye tracker which recorded participants' eye movement during the task resolution. We also analyzed them respectively in the above groups.

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Figure 44. Illustration of area of interest (AOI) for extracting eye tracking data

As the resolution time for successful groups (SS and FS) is different from one to another. We calculated the percentage of the fixation duration in the task resolution time (duration) and the number of saccades per second. For the participants who succeeded in the test, we also include their resolution time. Then we have the following tables:

Table 9. Fixation duration, number of saccades percentage and resolution time for FS (D) and FS (S)

FS (D)				FS (S)			
Participant	Fixation Duration_HP / Duration (s) (%)	Number of saccades / Duration (s)	Duration (min)	Participant	Fixation Duration_HP / Duration (s) (%)	Number of saccades_HP / Duration (s)	Duration (min)
P02	13,0%	0,34	5,00	P07	3,8%	0,15	2,38
P06	11,9%	0,31	12,33	P18	8,1%	0,27	5,03
P30	0,3%	0,01	12,43	P25	15,5%	0,55	7,63
P10	9,2%	0,26	13,5	P19	8,9%	0,46	9,52
P16	2,2%	0,09	14,43	P17	21,0%	0,59	9,67
				P31	3,9%	0,16	13,57

Table 10. Fixation duration, number of saccades percentage for FF (D) and FF (S)

FF (D)			FF (S)		
Participant	Fixation Duration_HP / Duration (s) (%)	Number of saccades_HP / Duration (s)	Participant	Fixation Duration_HP / Duration (s) (%)	Number of saccades_HP / Duration (s)
P01	5,6%	0,33	P14	2,3%	0,12

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P03	6,8%	0,21	P15	3,1%	0,10
P09	5,9%	0,21	P23	5,8%	0,35
P12	0,5%	0,05	P24	21,3%	0,67
P22	9,8%	0,31	P27	5,1%	0,15
P32	9,3%	0,35			
P35	14,8%	0,48			

Table 11. Fixation duration, number of saccades percentage for SS (D) and SF (D)

SS (D)				SF (D)		
Participant	Fixation Duration_HP / Duration (s) (%)	Number of saccades_HP / Duration (s)	Duration (min)	Participant	Fixation Duration_HP / Duration (s) (%)	Number of saccades_HP / Duration (s)
P33	0	0	1,17	P21	3,8%	0,24
P29	1,5%	0,06	11,00	P34	14,4%	0,55
P11	3,5%	0,29	13,80			
P08	1,8%	0,08	12,60			

\* The red background is not analyzed.

As we can see from *Table 9* that for the FS (S), the resolution time is related to the number of saccades and fixation duration by resolution time – the more time the participants spent, the more number of saccades they did and the more time they fixed on the HP. However, except for P31 whose number of saccades is 0.16.

For the FS (D), P16 and P30 did not seem to use the HP frequently, their data is rather small. This is also confirmed by their verbalizations (in the following section), they did not use HP intentionally, because they thought the HP showed all the errors they did in the pre-test. Thus, they preferred to stay fresh and would like to do the task on their own. We can infer that these two participants are quite autonomous that our tool won't help them. The way P02 used the HP is similar with the way of participants with static HP. She was the only one who discovered the problem that blocked her.

We do not see the insights from the other groups. However, these data will be analyzed combined with the verbalizations of the participants.

#### 5.4.2.2 RTA verbalization

We transcribed the participants' verbalizations which were recorded in the RTA session and we analyzed their common behavior in terms of their use of the HP from the beginning, on-going and the end of the task resolution.

There are only 2 valid participants SS (D) group, which are not comparable to the ones with the static HP, we described their behavior respectively:

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- P11 had many troubles with the operations of the game, he spent much time in adapting to the game. At the beginning, he looked at the last column of the HP, because he thought that it was the last composition he had done in the pre-test, which was the closest to the solution. In addition, he expected the HP to be highlighted. During the test, he tried to compare between the HP and what he was doing even the HP was not highlighted. He also looked for the way to highlight the HP. In the end, he was making shapes, and he looked at the highlighted area in the HP which made him think of the solution he had done in the pre-test, and then he succeeded. He was bothered by the operations of the game and thought that the HP should be highlighted even with one shape in the canvas. He liked the highlight, because if there was a lot of history, the highlight could save time for searching. But once he understood it, he made the figure and picked the last shapes by referring to the HP. The HP helped him recall his memory.
- For P29, she first scanned quickly the HP to see if there were some figures close to the solution, as she did not find it, she continued to do what she remembered last time. During the test, she focused on the highlight area of the HP and tried to refer to it because she thought it was most close to the solution. However, she tried many times but still did not make it. Then she did it on her own.

For the group SF (D), only the participants using the dynamic HP failed in the test while they both succeeded in the pre-test.

- P21: the order of the HP bothered her a lot as she stated, *"I'm having trouble of making sense of it."* and *"it prevented me from using it to my benefit."* She thought that the HP is chronologically displayed from left to the right. Therefore, she focused long time on the last part of the HP that corresponded to what she did, because she succeeded at the very end of the game last time. Besides that, the highlight of the HP for her is to invalidate her ideas (*"ah, that won't work."*).
- P34: at the beginning, P34 looked at the last two steps of the HP which were most possible to arrive at the solution. During the test, when the HP was highlighted, he avoided doing the same (*"j'ai changé, parce que je n'ai que ça me n'apporte rien. Parce que même si j'étais près, ..., aucun n'est bon, j'ai fait autre chose"*). When he lost attention, and did not know what to do, he looked at the HP to get some inspirations even when it was not highlighted. However, he also had difficulty in understanding what he had done (*"Juste me dire que je ne fais pas pareil, le point négatif. Je ne vois pas la logique de ce que j'ai fait. Je ne sais pas pourquoi j'ai fait ça"*). When he was close, he was not aware of that. The HP didn't help him get out of his own thought (perspective) and see it globally (change to another perspective).

Both P21 and P34 thought that the entire HP was all the errors they had done, so the highlight for them were to invalidate what they were currently doing. Moreover, they both have trouble in understanding their HP. This is also consistent with the semantic evaluation in their perception for "understanding" (see

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Table 15).

For comparable reason, we focus on the groups FS (D), FS (S), FF (D) and FF (S). We would like to see the common behavior and patterns from the participants using the HP as well as to see the differences between groups. On this account, we have listed the sentences most expressed by these 4 groups of participants from the experience maps<sup>12</sup> that we drew (see A.2.4 Experience map) to illustrate their common and different behavior regarding the stages (the beginning, on-going and the end) during the test (See *Table 12*). This can help us see visually and clearly the stages that they experienced and the touch points.

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<sup>12</sup> Experience map visually shows the journey that these 4 groups of participants have experienced while using the HP in the task resolution.

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Table 12. Common verbalization by different groups (blue areas are only for dynamic HP)

Group	Participant	Begin		Highlight		General behavior			Awareness			Feeling				
		I was looking for if there were some figures in my HP which were close to the solution.	The HP showed me the errors that I have done last time and I tried to avoid reproducing the same.	Highlight, what else can I do with the same base highlighted? (Refer)	Highlight, I should do something else. (Invalidate)	I looked at the HP to see if I haven't done before. (Compare and verify)	I was scanning the HP to see if there were some examples that can help me. (Inspiration)	I felt like it always lacked a piece. I was so close.	I realized that I always repeat the same thing as I did in the HP.	I realized that I never did this before.	I realized some shape or combinations that I did in the HP did (not) work.	I felt less lost with the HP.	It did not help me, the history path	The HP did not allow me to have an insight to explore more.	The HP (highlight) is a little disturbing.	
FS (S)	P07	x	x								x					
	P18	x	x								x					
	P25	x					x				x					
	P19	x	x				x		x	x	x	x				
	P17		x				x		x		x	x				
	P31		x						x	x	x	x				
FF (S)	P14	x					x	x	x	x						
	P15	x					x		x				x			
	P23	x				x	x	x		x						
	P24	x	x				x		x							
P27		x				x							x	x		
FS (D)	P02		x	x		x	x				x	x				
	P06	x			x	x	x									
	P30				x											
	P10		x		x	x	x									
	P16													x		
FF (D)	P01						x							x		
	P03	x		x	x	x	x		x							x
	P09			x	x		x	x	x							x
	P12	x		x			x	x						x		x
	P22	x			x		x	x	x		x	x				
	P32	x			x		x	x			x					
	P35	x			x		x									x

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- **FS (S)**, there are 6 participants: P07, P17, P18, P19, P25 and P31. They are more actively searching for the information instead of being received passively as in the dynamic history path. The key difference from the dynamic HP is that they finished by finding key path in the HP which unblocked their difficulty in the end.
  - *Start*: 4 out of 6 (P07, P18, P19 and P25) tried to find if there was something close to the correct solution in the HP. 5 out of 6 (P07, P17, P18, P19 and P31) looked at their errors in the HP trying not to do the same.
  - *On-going*: 3 out of 6 (P17, P19, P25) scanned the HP to see if there were some examples that can inspire them. From the HP, 3 out of 6 (P17, P19 and P31) realized that they always repeated the same combinations in this session as they had done last time but did not work; among them, P19 and P31 realized that they had never tried some combinations last time.
  - *End*: 4 out of 6 (P07, P17, P18 and P25) realized that they always put some shape in one position which did not work last time, they were unblocked from the HP, which led them to the correct solution. P17, P19, P31 felt less lost with the HP.
- **FF (S)**, there are 5 participants: P14, P15, P23, P24 and P27.
  - *Start*: 4 out of 5 (P14, P15, P23 and P24) tried to find if there was something close to the correct solution in the HP; among them, P14 and P15 did not know what to do with the HP since they showed all the error that they did last time. P24 and P27 looked at their errors in the HP trying not to do the same.
  - *On-going*: all of them scanned the HP to see if there were some examples that can inspire them; among them P23 also tries to compare and verify if she had done the same thing in the HP. P14 and P15 realized that they always repeated the same combinations in this session as they had done last time in the HP but did not work. P14 and P24 realized that they had never tried some combinations last time. P23 realized that some combinations in the HP did not work. P27 tried to explore other possibilities from HP, but he did not get inspired.
  - *End*: they were frustrated that they did not find the solution. However, the static HP made some of them (P14, P15, P23 and P24) aware of some combinations that they always repeated, some combinations they had done but did not work and some combinations that they had never done last time. The HP helped to develop their thinking.
- **FS (D)**, there are 5 participants: P02, P06, P10, P16, and P30. P16 and P30 did not look at the HP so much, particularly for P30, she did look only once because the HP was highlighted, and she changed what she was doing immediately to turn it off. P16 did look at the HP for a few times but unconsciously.

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- *Start*: they thought that their HP contained the errors that they did last, so they kept not looking at it to get some new ideas. Po2 and P10 looked at their errors in the HP trying not to do the same; and Po6 tried to find if there was something close to the correct solution in the HP.
- *On-going*: Po2 tried to make some modification based on the highlight figure in the HP. 3 out of 5 (Po6, P10 and P30) tried to invalidate what they were doing when the HP was highlighted (see Table 12: *dark blue*). When the HP was not highlighted, 3 out of 5 (Po2, Po6 and P10) tried to compare and verify if they had done the same thing in the HP (see Table 12: *yellow in general behavior*). And they scanned the HP to see if there were some examples that can inspire them.
- *End*: except for Po2 who found the problem which blocked her in the HP, the others, they succeeded all by themselves. Po2 expressed her preference to the HP and that she discovered the problem that blocked her from the HP. (“I mostly looked at the end, I realized that it was the square that was the problem, and I told myself in which, when, I put the square that was not the weird thing<sup>13</sup>.”) Po2 also said that with the HP, she was more assured, and she could spend time analyzing and thinking than the first time.
- **FF (D)**, there are 7 participants: Po1, Po3, Po9, P12, P22, P32 and P35.
  - *Start*: 5 out of 7 (Po3, P12, P22, P32 and P35) tried to find if there was something close to the correct solution in the HP.
  - *On-going*: when the HP was highlighted, 3 out of 7 (Po3, Po9 and P12) tried to make some changes based on the highlighted ones (see Table 12: *light blue*); 5 out of 7 (Po3, Po9, P22, P32 and P35) tried to invalidate what they were doing (see Table 12: *dark blue*);. When the HP was not highlighted, all of them scanned the HP to see if there were some examples that can inspire them; Po3 also tried to compare and verify if they had done the same thing in the HP. P22 realized that she always repeated the same things that she had already done in the HP but did not work. P35 realized where the problem possibly was from the HP.
  - *End*: they were frustrated that they did not find the solution. Some of them felt very close to the solution, but still did not come out of their deadlock. P22 felt less lost with the HP no matter if it can really help her or not. It is like a psychological comfort. Po3, Po9, P12 thought that the highlight is a little disturbing, because sometimes it made them think that it could be a solution, however, it was not. It distracted from what they were doing, it is kind of an

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<sup>13</sup> Original sentences in French : « J’ai surtout regardé jà la fin, j’ai réalisé que c’était le carrée qui posais le problème, et je me suis dit dans quel, à quel moment, j’ai mis le carrée qui ne faisait pas le truc bizarre. »



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interruption. What's more, the highlight restricted their ability to exploit what they did before, which means to find the elements that could construct the solution. P12 and P35 clearly stated that the HP did not allow them to have an insight to explore other possibilities.

We can see that most of the participants they have common behaviors in using the history path with both dynamic and static feature. FS (S), FF (S) and FF (D) looked at the HP at the beginning of the test, because they wanted to see if there were some figures that they had done previously were close to the solution. This is almost a common behavior among these three groups.

The static HP was used as a representation of all the trials and errors that had been done by the participants, trying not to reproduce the same. This behavior is evident among the participants who succeeded in the test (FS (S) and FS (D)).

The dynamic history path during the test, is mostly for them to avoid reproducing the same errors as they did not succeed last time (3 out of 5 in FS (D) and 5 out of 7 in FF (D)). The highlight although, saved them time to invalidate some compositions, discouraged them to search for useful information, as it thought for them. They were controlled by the highlight which limited their capability of exploration other possibilities to the solution.

Nearly all the participants (18 out of 23) looked at the HP for inspirations, which means that the participants with the dynamic HP also used their own HP in static way.

What is interesting in the table is the column "Awareness" that FS (S) and FF (S) realize that HP helps them visualize their mistakes and the inspiring paths. This is more evident in the static HP than the dynamic HP (only 3 participants). The static HP, during the test, is for them to both avoid and refer. They are more actively searching for the information instead of being received passively as in the dynamic history path. The static HP is an active support to think contrary to the dynamic HP that blocks reflection.

In addition, regarding the feelings, several participants were also expressing that the HP was helpful for them to solve the puzzle. Some also thought that the highlight, although attracted their attention, was disturbing and distracting.

#### 5.4.2.3 Usage form in terms of eye movement

In order to visualize their usage of HP during the entire journey more intuitively, we also draw the usage form with regard to their eye movement towards the HP (See Figure 45).

Note that there were several inaccuracies in several test, we should take this into account. P01 is the first person to test our prototype history path. At that time, there were some bugs in the prototype, including the inaccurate highlights. Therefore, P01 lost confidence in the HP as the highlight was not accurate. Eye tracker did not capture enough gaze points of P29, as the gaze weight is only 20%. This may be due to the user moving too much during the test so that the eye tracker does not capture eye movements. Therefore, there were maybe inaccurate fixation.

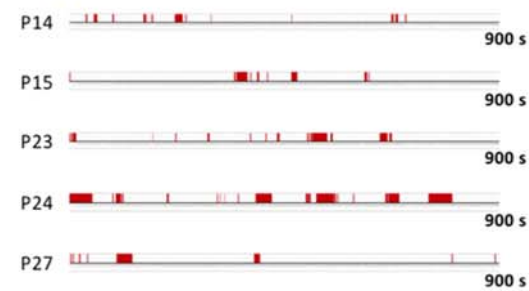
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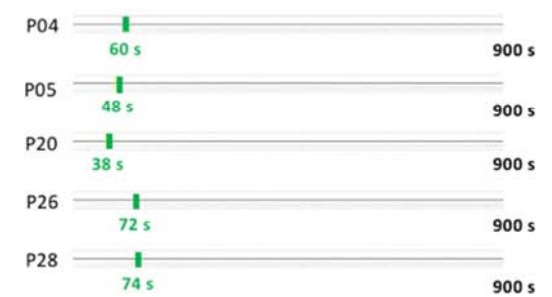
### FS (S)



### FF (S)



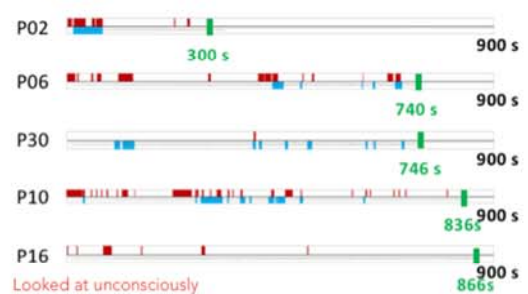
### SS (S)



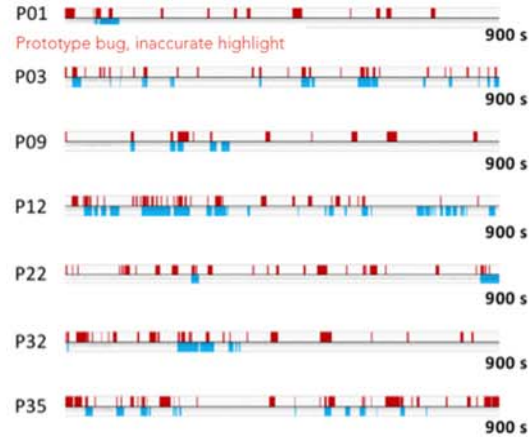
## Statique

### Dynamique

### FS (D)



### FF (D)



### SS (D)



### SF (D)

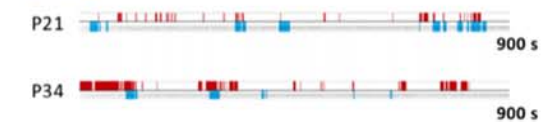


Figure 45. HP usage pattern: top for static, and bottom for dynamic; red bars stand for fixation and blue bars for highlight only for dynamic HP

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From the usage form, we identify some common patterns:

The autonomous: P16 and P30 expressed that they did not use the HP and preferred to find the solution on their own, which is also consistent with their fixation data. These two are so autonomous that the HP won't help them. This kind of feature is not suitable for them.

The observers: FS (S) (P18, P25, P19 and P17) and FS (D) (P02, P06, P10) are who succeeded in the test, looked at the HP intensively as a static image at the beginning. The HP helps them solve the puzzle.

P31 saw the HP as a support, as she stated "Je me sens moins seule" (I feel less alone) with the help of the HP.

The failers: FF (S), FF (D) and SF (D) rarely looked at the HP intensively at the beginning (except for P34). On the other, hand, they looked at it very shortly and frequently. This is more evident for the dynamic HP when it was highlighted, appealing to their attention so that they had to look at it. The highlight interrupted their continuous reflection. We can infer that they took long time to make sense of what they had done and explore what to do.

We examined the resolution time for those who succeeded in the test (FS) and their usage form. It shows that the average resolution time of the task for the participants with static HP ( $t_{FS(S)}$ ) is shorter than those with dynamic HP ( $t_{FS(D)}$ ):

$$t_{FS(S)} < t_{FS(D)}$$

Based on Edmund Husserl in his *On the Phenomenology of the Consciousness of Internal Time* (1991), the structures of consciousness that make possible the experience of time. Then, we can infer that the time of constitution of consciousness of the HP is shorter in the perception of dynamic than the perception of static. Then it is easier for them to have a synthesis about what they have done in the past.

### 5.4.2.4 Semantic evaluation

In terms of the subjective measures, the participants were asked to rate how they perceived the history path in the resolution of Tangram. We listed their rating based on the 4 above groups and compare the dynamic HP to the static HP, we first present the ratings between FS (D) and FS (S) (See *Table 13*).

Table 13. Semantic evaluation of the history path for FS (D) VS. FS (S)

Participants	FS (D)							
	Understanding	Intuitive	Fun	Consistent	Guiding	Useful	Pleasant	Innovative
P02	5	5	3	5	1	4	4	5

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P06	4	5	3	3	4	3	4	5
P10	5	3	3	4	3	4	3	4
P16	5	5	3	3	3	1	3	5
P30	5	5	4	5	3	3	4	2
<b>Mean</b>	<b>4,8</b>	<b>4,6</b>	<b>3,2</b>	<b>4</b>	<b>2,8</b>	<b>3</b>	<b>3,6</b>	<b>4,2</b>

FS (S)								
Participants	Understanding	Intuitive	Fun	Consistent	Guiding	Useful	Pleasant	Innovative
P07	3	3	4	4	4	4	4	5
P17	5	4	5	4	5	5	5	5
P18	4	5	3	5	3	5	3	5
P19	5	3	3	5	3	3	5	5
P25	5	5	4	4	4	5	4	3
P31	5	4	4	5	3	5	5	3
<b>Mean</b>	<b>4,5</b>	<b>4,0</b>	<b>3,8</b>	<b>4,5</b>	<b>3,7</b>	<b>4,5</b>	<b>4,3</b>	<b>4,3</b>

The above table shows the different ratings of the two groups: FS (D) and FS (S). As we can see from the table, there are some common points in terms of *understandable*, *consistent* and *innovative*. The participants in FS (D) thought that the dynamic HP was more intuitive compared to the static HP. This means that the participants in FS (D) understood easily the highlight but in the wrong way. They perceived the highlight as a way to invalidate their ideas rather than a way to explore other possibilities. In this case, the perceived connotations as well as the perceived usage of the dynamic HP serve as a memory substitution rather than a memory supplementation.

There are differences in terms of *guiding*, *useful* and *pleasant*, the ratings of participants with the static HP are higher than those with dynamic HP (guiding: 2,8 vs 3,7, useful: 3 vs 4,5 and pleasant: 3,6 vs 4,3). There is a great difference in usefulness between the static HP and the dynamic HP. The participants with the static HP thought it more useful than those with the dynamic HP.

Then, we compare the ratings between FF (D) and FF (S) which are shown in the following table (See Table 14).

Table 14. Subjective evaluation of the history path for FF (D) VS. FF (S)

FF (D)								
Participants	Understanding	Intuitive	Fun	Consistent	Guiding	Useful	Pleasant	Innovative
P01	3	4	3	2	4	2	4	4
P03	4	4	5	5	4	4	5	4
P09	3	5	3	5	2	3	3	3
P12	4	2	4	3	1	5	4	5

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P22	4	2	4	4	3	4	5	4
P32	5	5	3	4	5	3	5	5
P35	5	4	3	5	3	5	4	4
<b>Mean</b>	<b>4,0</b>	<b>3,7</b>	<b>3,6</b>	<b>4,0</b>	<b>3,1</b>	<b>3,7</b>	<b>4,3</b>	<b>4,1</b>

FF (S)								
Participants	Understanding	Intuitive	Fun	Consistent	Guiding	Useful	Pleasant	Innovative
P14	5	5	3	2	3	2	5	4
P15	3	5	5	5	3	4	5	5
P23	4	4	4	5	3	5	4	4
P24	4	4	3	3	4	4	4	4
P27	5	5	4	4	3	4	4	4
<b>Mean</b>	<b>4,2</b>	<b>4,6</b>	<b>3,8</b>	<b>3,8</b>	<b>3,2</b>	<b>3,8</b>	<b>4,4</b>	<b>4,2</b>

As for FF (D) and FF (S), there is no much difference except for intuitive which is 3,7 for FF (D) and which is 4,6 for FF (S). This lower rating of FF (D) was because they did not use the dynamic HP as intensively as the participants in FS (D), which can be confirmed by their fixation duration in *Table 9* – FS (D) and *Table 10* – FF (D). The participants in FF (S) thought the static HP was more intuitive than the dynamic HP. We can infer that the failure in the test is not the cause of the intuitiveness. On the other hand, FF (S) gave the same note as FS (D), because they did not blame their failure on the system, but themselves.

Table 15. Subjective evaluation of the history path for SF (D)

SF (D)								
Participants	Understanding	Intuitive	Fun	Consistent	Guiding	Useful	Pleasant	Innovative
P21	3	2	3	1	4	2	2	5
P34	2	3	5	3	4	4	3	3
<b>Mean</b>	<b>2,5</b>	<b>2,5</b>	<b>4</b>	<b>2</b>	<b>4</b>	<b>3</b>	<b>2,5</b>	<b>4</b>

From *Table 15*, only the participants with the dynamic HP failed in the test. Compared with the first time when they have succeeded, they failed the second time. They did not perceive the HP as intuitive and useful as the other groups above.

We will analyze these measures altogether regarding to the static compared to the dynamic and the success compared to the failure and discuss afterwards.

### 5.4.3 DISCUSSION

When the task is too easy for users, they do not need a provenance tool to supplement their memory for problem-solving, as the participants in SS (S) and P33.

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There are also two people (P16 and P30) who expressed that they did not use the HP, which is consistent with the eye tracking data (few fixation). They prefer to solve the problem themselves. Therefore, our HP will not help them. This kind of feature is not suitable for them.

Then, we compare the results from two dimensions: success vs. fail and static vs. dynamic.

#### 5.4.3.1 Success vs. fail

For whom succeeded (FS) in the test, they had a relative intensive fixation on the HP, especially at the beginning of the test. And the sooner they focused intensively on the HP, the less time they spent to solve the puzzle. They looked at the HP first except for P17, and then they looked less, they found some ideas from the HP, and then they continue to focus on their task resolution;

For whom failed (FF) in the test, the participants in FF(D) looked at the HP discretely throughout the session, which is not enough for them to come to a conclusion / constitute a summary; the participants in FF (S), except for P24 who focused longtime on the HP throughout the session, mainly focused intensively in the middle or end of the session. They had a very short interaction with the HP and they looked at the HP very frequently.

Therefore, long fixation particular at the beginning of the session probably leads to the success, because it may stimulate consciousness which enables analyzing and summarizing what they have done in the past which may be used for the future. The long fixation could enhance the working memory.

#### 5.4.3.2 Dynamic vs. static

We are interested to see the extent to which the static or dynamic HP could permit memory supplementation that opens scope of possibilities and promotes more exploration of the problem-solving task. From the results, it seems that the memory supplementation is in favor of the static rather than the dynamic.

The participants used the dynamic HP (FF & FS (D)) in two ways: looked at it when highlighted, referred to it when not highlighted (as in static). The participants with the dynamic HP looked at the HP intermittently and frequently during the test, especially when highlighted. They are controlled by the HP (highlight), as the highlight appealed to their attention, so they have to follow it. However, with the static HP, the participants have the whole view of HP displayed in front of them, and they have the initiative to focus on it longer or shorter (the fixation duration).

This can be explained by the constitution of consciousness, based on Edmund Husserl in his *On the Phenomenology of the Consciousness of Internal Time* (1991) and Bernard Stiegler's *Technics and Time* (Stiegler, 2010):

Firstly, the disposition of the HP both static and dynamic serve as a tertiary memory according to Bernard Stiegler's *Technics and Time* (Stiegler, 2010). Tertiary memory was

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developed by Stiegler through the primary and secondary retention or memory of Husserl. The primary retention belongs to the act of perception, secondary retention or memory belongs to the imagination and the tertiary retention or memory belongs to the exteriorization of memory (Roberts, 2006).

Take an example of melody that was used by Husserl to study the consciousness. When listening to music, we use the current perception to form the "first memory." After listening to the music, we use imagination to form a "second memory". The key issue here is that perception and imagination are not completely separated. Each memory has a selection principle. Any perception has an imaginary component, and the imagination also has a perceptual component. What Stiegler is concerned with is how to make it possible to listen to the music repeatedly. This is obviously thanks to the tertiary memory, which is the various recording techniques. Recording technology makes it possible to repeatedly listen to the music and watch the movies. In this repetition, not only can new meanings be obtained, but also deviations from previous memories can be corrected. The history path records the participants' past action in the pre-test, that can modify their perception of the problem-solving to some extent. Then to what extent this change of perception can be made depends on the property (dynamic or static) of the history path.

The phenomenology of consciousness explains how we experience time. An object is moving in the space, it continues in the time. Our view of time is based on the comparison with the object moving in the space. Our consciousness is inseparable with the movement of this object in the space. Stiegler compared consciousness to movies. when We are seeing a movie, we have to follow its story to make sense of it. Our consciousness of time is synchronized with the time passed on the movie. Similarly, the temporal object such as the dynamic HP controls the spatial exploration, which hinders the constitution of consciousness. Therefore, the dynamic HP limits the scope of possibilities. It serves as a memory substitution.

On the contrary, the internal time is irrelevant to the movement of an object, the phenomenon of consciousness is not in the specific space, it comes out one by one. We can get an experiential consciousness of internal time. As people can play back or fast forward a recorded movie as they want, it allows more exploratory actions that open up new scope of possibilities. They are in the lived experience related to the consciousness and exploration of activity. With the static HP, the participants have the whole view of HP displayed in front of them, and they have the initiative to focus on it longer or shorter. When the participants looked at the HP several times, it is continuous in the internal time, and our consciousness has indeed experienced this continuation. But at the same time, it is several phenomena, and these phenomena coexist in their consciousness. In the consciousness of internal time, people objectify the content of consciousness. This process of objectification is the process of constructing consciousness through the understanding and the content of consciousness (P. Li, 1998). The static HP enables the participants to actively search for useful information that they are autonomous to determine which part of HP to avoid, which to reuse, etc. It allows more exploration on the static HP than the dynamic. The



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participants have more control on the static HP instead of being controlled by the dynamic HP.

The feature of dynamic history path did not produce the positive effect as we hypothesized. We initially assumed that the dynamic HP would be a natural coupling through which provokes a further exploration of action possibilities for solving the Tangram puzzle. On the contrary, the static HP which stimulates active explorations and constructs the consciousness of what they have done before. The static HP opens up new scope of possibilities, which arises memory supplementation.

## 5.5 CHAPTER SUMMARY

This chapter, we conducted two experiments in integrating the concept of history path as a memory support for users to re-commit an interrupted or suspended task. In the framework of minimalist experiment, we develop a prototype through the Tangram game, hoping to find the technical conditions of emerging a positive experience.

From the first Tangram experiment, we found that the concept of the history path served as a cognitive support for problem-solving process. In addition, we discovered the two ways of using the history path by users: use it statically and use it dynamically. However, the static history path chronologically displayed took users a lot of time to search the information and compare between what they are doing and what they did before. Then, we hypothesized that a dynamic history path might be a natural coupling with users in resolving the Tangram puzzle. This experiment gave us an insight for designing the "in hand" mode history path, which we integrated in the second Tangram experiment.

The second Tangram experiment shows that the static HP can stimulate more exploration and facilitate the constitution of consciousness than the dynamic one. The experiment showed us that although the history path did not help users change their perspectives of seeing the visual shapes, the highlight feature saved time for them to look one by one in the history path, which indicates that the dynamic history path improves their productivity. However, the highlight may also produce wrong information that as the participants failed last time, they treated the highlight as invalidation of hypothesis. However, many participants expressed their expectation of the highlight as the volume of history increases, it is better to see the highlight instead of searching.

In visual data analysis, there is no absolute right or wrong answer, the objective is to find the root causes of a business problems for decision making. Then, it is interesting to have this dynamic history path to facilitate the analysis process and re-commit the task. In this chapter, we apply the history path framework in an analytic product – SAP Analytics Cloud (SAC).

## CHAPTER 6 TEST THE HISTORY PATH FRAMEWORK IN AN ANALYTIC APPLICATION

*"Design is an opportunity to continue telling the story, not just to sum everything up."*

— Tate Linden American branding and strategy expert

*"Design brings content into focus, design makes function visible."*

— Jennifer Morla, president and creative director of Morla Design, Inc.

This research took place in the context of analytic applications design at SAP. In the previous chapter, we tested the design framework of history path through a minimalist experiment. In this chapter, we present a proposal to transpose the proposed framework history path to an analytic application – SAP Analytics Cloud.

SAP Analytics Cloud (SAC) (See Figure 46), developed by SAP, is an all-in-one cloud platform for business intelligence and organizational planning, enhanced with the power of predictive analytics and machine learning technology. It allows users to have the capabilities of data manipulation, visualization and analysis, financial planning and predictive forecasting. Built on SAP cloud technologies, it allows, in just a few clicks, to create interactive dashboards accessible from any workstation. For more information, please visit the website: <https://www.sapanalytics.cloud/>.

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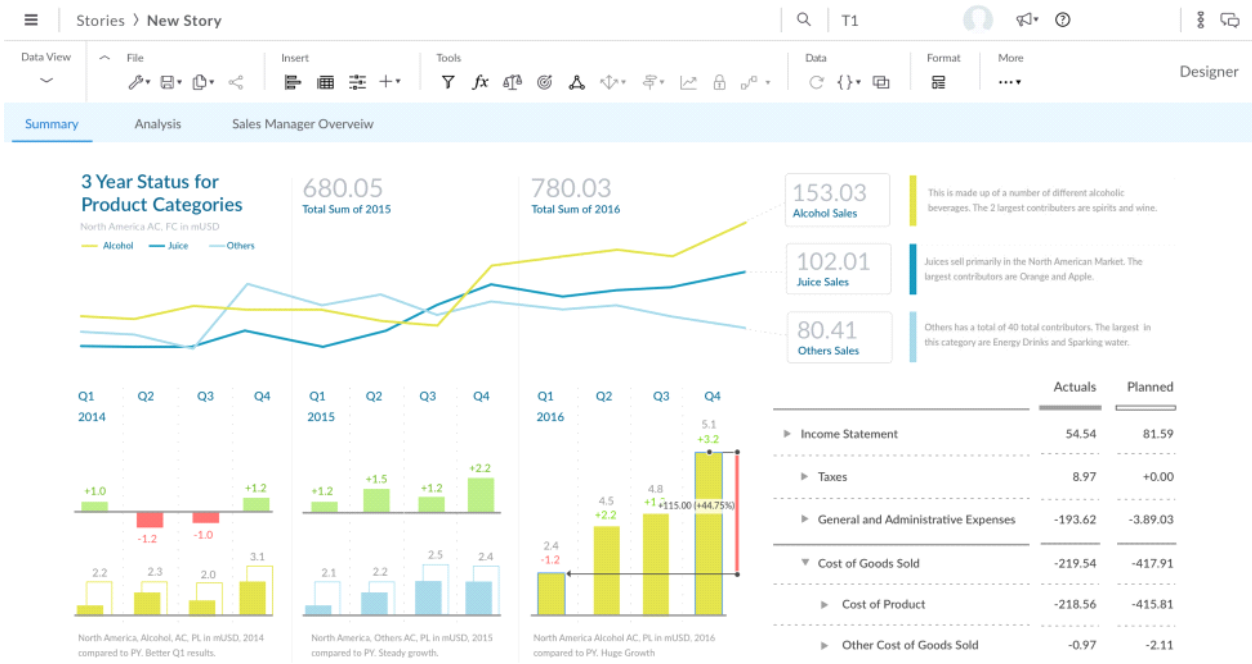


Figure 46. SAP Analytics Cloud -- creating a story that contains a series of charts.

We are going to propose a mockup of the application of the HP in the context of creating a story based on *SAP Analytics Cloud*. This mockup is built only for this research purpose and is still at the design stage, which means that it is not released in the product.

## 6.1 LIMITATIONS OF THE TANGRAM EXPERIMENT

The initial idea of using Tangram puzzle in the experiment is that it can simulate a problem-solving task such as an analytical task. We hope to understand the user behavior in the problem-solving process. In terms of the memory supplementation, the discovery in the research problem is very rich, and it helps us rethink the design for opening the scope of possibilities in the interaction and the support tool as media between users and the task. However, it also has some limitations in terms of the transposition to the analytics context.

Because the participants think that what has been done last time (the HP) are the wrong trials and errors without so many values. Therefore, the fact of failure in the pre-test influences their attitude to the HP, no matter it is static or dynamic. However, in the real case of analytics, different from the puzzle Tangram that allows the player to find an absolute answer, visual data analysis tasks are usually exploratory without a unique answer. The goal of the latter one is to identify the root causes of a business question, such as why the employees leave the company this year, why the sales revenues dropped down this semester, etc. Therefore, the Tangram game is not completely analogy to a visual data analysis task.

In this case, the highlight feature, although seemed disturbing (because it provides the wrong clue in the Tangram), can save time for user looking one by one to find the right path. This has been indicated by the participants who expected the highlight. They stated that it

is better to see the highlight instead of searching one by one, because the history could be voluminous in reality.

In all, due to these differences, users' judgement of the HP could be different as well as their attitude to the highlight. Then, it could be interesting to have this dynamic history path to facilitate the analysis process and re-commit the task.

## 6.2 DEMONSTRATION OF THE HP IN SAP ANALYTICS CLOUD

With the study of user research and the user workflow of a visual data analysis task, we noticed that users usually use certain dimensions and operations in the same analysis repeatedly. This is similar with the participants' strategy solving the Tangram puzzle, such as always put the square and a parallelogram together. Similar, users focusing on an analysis of sales revenue are always use the product category as a start of each exploratory analysis. Then this discovery allows us to extract the commonly used dimensions and operations (filter, drill down, etc.) as a basis to construct the history path in the analytics context.

We took a simple user scenario based on the human resource (HR) dataset that is downloaded in the [kaggle](#), a website, providing a resource for competitive data science and machine learning.

The user scenario goes as follows:

*Joan is asked to find out why do our employees leave the company? (business question)*

*She then comes to SAP Analytics Cloud to conduct the visual analysis. She made a story with the different charts she created.*

*While Joan is working on her task, she receives another task which is more urgent, then she saved the story in SAP Analytics Cloud before starting with the new task.*

*Three hours later, Joan comes back to her suspended task, then she goes to the saved story. However, she couldn't think of where she left off, and what she was going to do next. She clicked on an icon to trigger the history path.*

We designed in a static mockup a proposal to integrate a history path in SAP Analytics Cloud. This proposal is only built in the purpose of this research; it is not released in the product and currently analyzed by SAP regarding its relevance for the product and eventually test it in the future.

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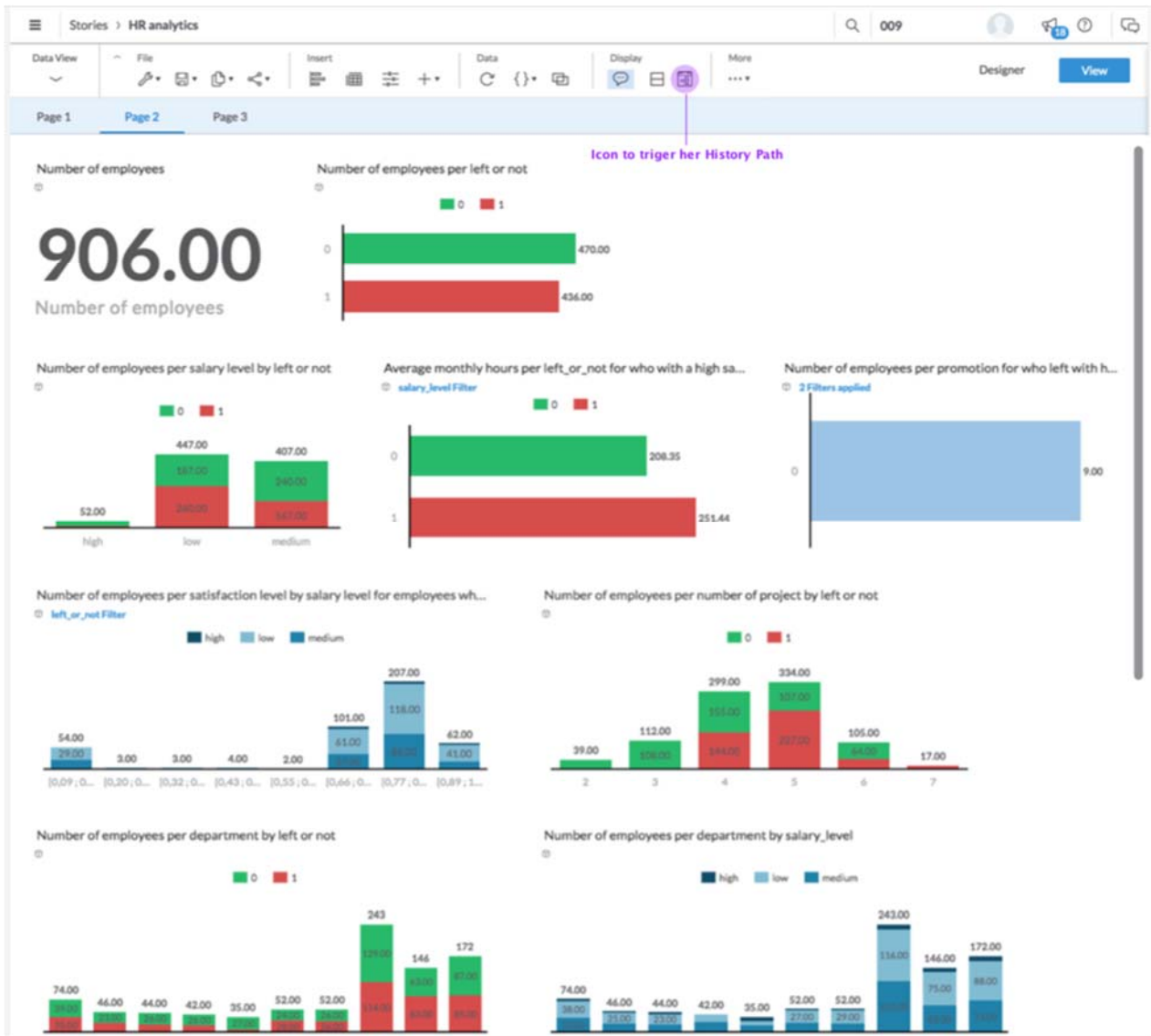


Figure 47. Mockup in SAC story – the icon to trigger the HP

When the button is clicked, the history path will be presented below the main story, half and half presented by default, then the user can enlarge the panel as well (see Figure 48). The HP is presented in the tree diagrams. As we mentioned, users are often used some common dimensions and operations. In this case, Joan often uses the dimension “left\_or\_not” to start her analysis. Based on this dimension, she adds other charts. During the analysis, she also adds some filters. If the charts are created based on the same filter, they will be two branches of the same operation. This HP showed a workflow of Joan’s analysis and the relationships between charts.

# TEST THE HISTORY PATH FRAMEWORK IN AN ANALYTIC APPLICATION

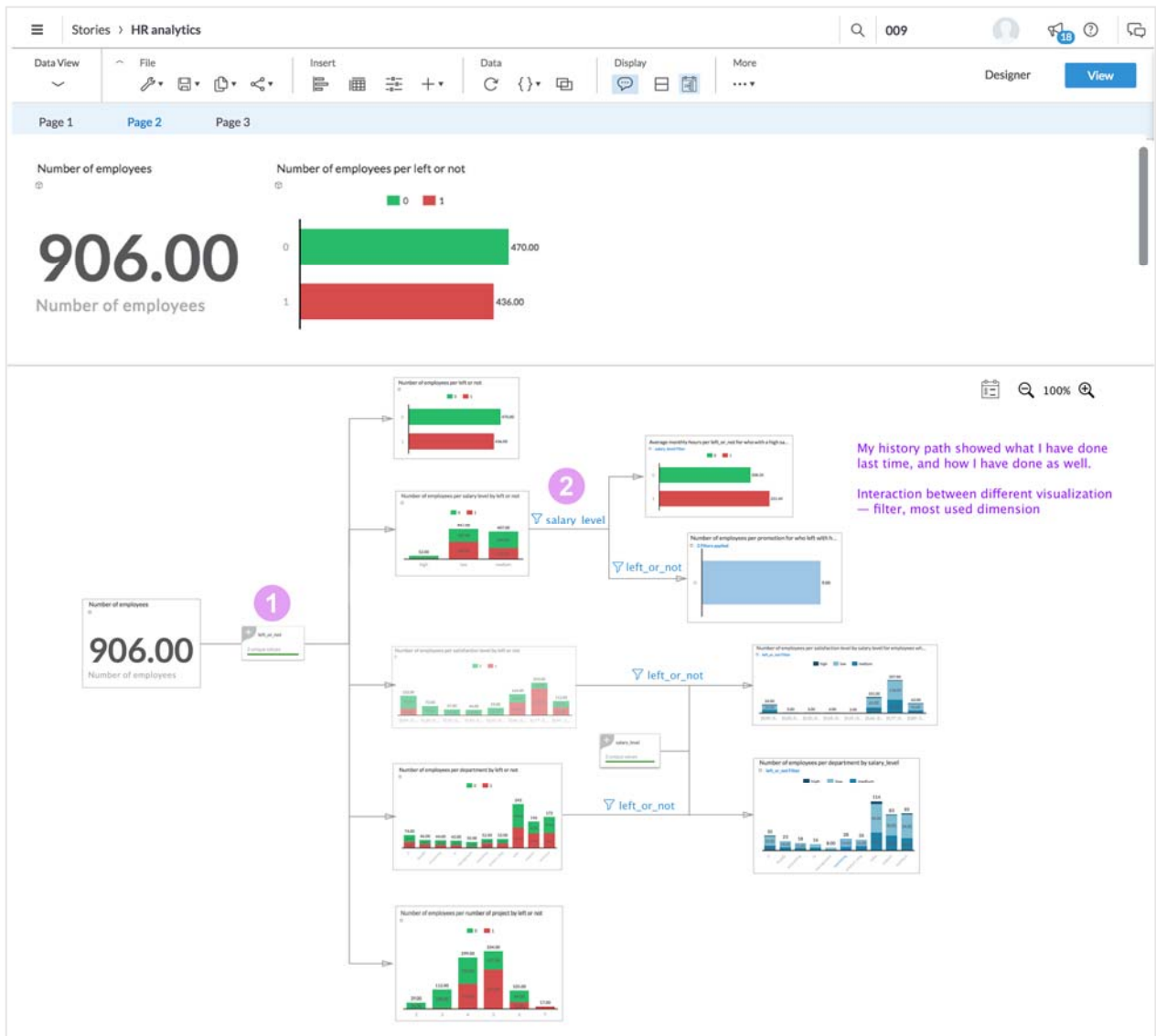


Figure 48. Representation of history path: 1) the driven dimension from which the user starts analysis; 2) common filter

If Joan wants to clarify how she created or why she created on chart in the story, clicking on the chart allows her to visualize the whole path to this chart (See Figure 49). This may help her recall what the previous steps are done before. When the user adds a new operation directly on one chart that it is replaced by another, it will be shown semi-transparently (See Figure 49 – 3).

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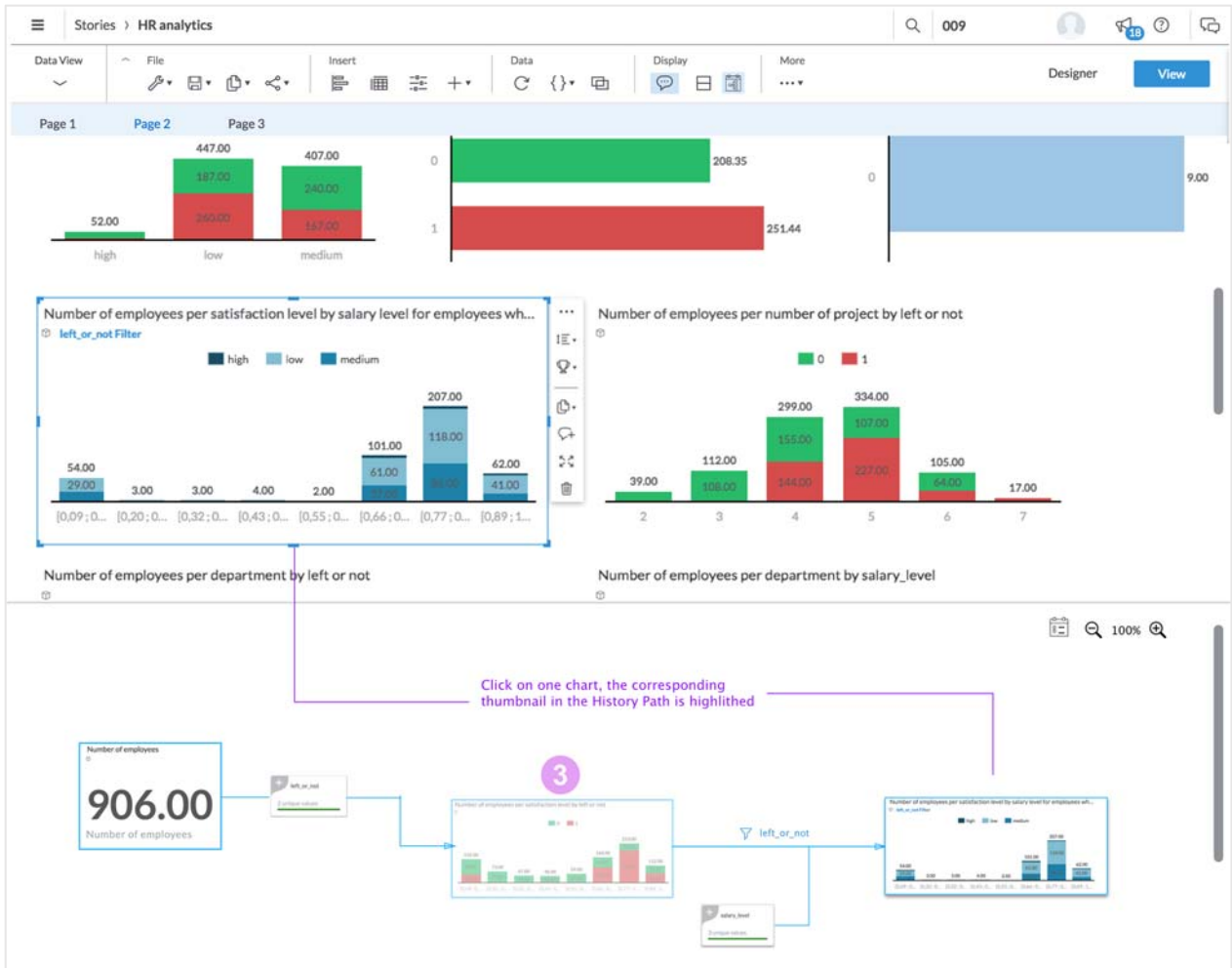


Figure 49. Highlight the previous path: 3) the chart is semi-transparent, because the next chart replaced it in the story

This user scenario is a simple one to demonstrate how we could transpose the history path in a professional analytic tool like SAP Analytics Cloud. This proposal is currently at research state and haven't been implemented in the product. The prototype has to pass the SAP design stages: UX validation, testing and iterations

At this stage, we have presented this mockup to SAP designers, and we acquire some positive feedback and suggestions.

- The root cause analysis is a common strategy that users use, and it is interesting to show them their history path which facilitates the "come back and forth" among the different charts and visualizations. This is what lacks in the current solution in SAP.
- Users care about the middle steps of analysis as well as the end result. It is common for them to look for the intermediate analysis steps to figure out a problem or restart another exploration.
- As the analysis process could be more complicated, then the volume of the history should be considered.

## TEST THE HISTORY PATH FRAMEWORK IN AN ANALYTIC APPLICATION

- In terms of collaborative work, the history path could be used by different users, such as an analyst who does a report and a consumer who reads the report. The history path could be useful for the consumer to understand the analyst's work.

To improve the HP design and consider more complex analytical process would be the perspective.



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## CHAPTER 7 CONCLUSION AND PERSPECTIVES

*"People do not like to think. If one thinks, one must reach conclusions.  
Conclusions are not always pleasant."*

*— Helen Keller, American author*

In this last part, we give a review of the work presented throughout this manuscript and a discussion on their impact on the methodology and professional practices. We started from a new design perspective, which highlights the sensorimotor factor in user experience design. A design framework was developed to support the design of problem-solving tools and its application in BI and analytic domain. Finally, we give some of the limitations of this work and opportunities for future research.

### 7.1 CONCLUSION

The rapid growth of the volume of data poses challenges for analyzing data, which leads to a change in the design of BI and analytic applications. Besides BI experts, more end users are demanding to conduct visual data analysis. Users' expectation of simple interaction for complex analysis process to facilitate their decision making is crucial for designers to enhance user experience. In addition, from the analysis of user studies and analytics task flow, we found the complexity of analytics process and the nature of multi-tasking of most of business users in their daily work. These two factors lead to memory overload and task interruption or suspension phenomena that influence the task performance and user experience. Users are getting used to keeping track or review their previous analysis steps that serve as a memory aid. It is beneficial to design a history tool to help users better recommit the interrupted or suspended tasks.

Positioning of our research on the enactive approach and sensorimotor of perception allowed us to see that interaction histories can be seen as an alternation of the "in hand" and "put down" modes, constructing a relationship between the user and the task. The objective was then to design a memory tool as a memory supplementation that can extend the user's perceptual capability. To address these challenges, this thesis research focused on evaluating the extent to which we can enhance user experience by designing a memory supplementation support in the context of BI and analytic applications. We especially worked on how to engage users to re-commit an analysis task which has been interrupted or suspended.

In the first place, to design the appropriated interaction in the interactive applications, we have looked at how people perceive the user interface and interaction of interactive

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applications. We conducted an exploratory study that analyzed the perception of interactive applications by experienced designers. The emerged perceptual qualities allowed us to construct our own evaluation dedicated to our context and guided us for the design taking into account these criteria.

In the second place, we conducted two experiments within the framework of a minimalist experiment to see if it is possible to design a memory supplementation for a problem-solving process in the context of task interruption. We proposed a provenance function – history path that captures users' action history. With this function, we developed a prototype integrated in a Tangram game that simulates a problem-solving task. This tool allowed us to ask the questions of memory load related to the task interruption. The first experiment allowed us to continue the work related to memory load in the context of task interruption by confirming the function of history path. For the second experiment, we redesigned the history path that captures users' interaction history and represents it in a tree-diagram by extracting their common usage patterns. We evaluated it in two types of history path, a static one and a dynamic one. We initially hypothesized that the dynamic history path that automatically responds to the user's current action will produce a natural coupling with the task that makes memory supplementation happens. However, the evaluation results showed us the contrary outcome. The dynamic history path did not help users greatly for resolving their task but looked like as being another kind of interruption that hindered the constitution of consciousness of the history steps and the current reasoning process. Users lost control of their own history path, and were more like being controlled by the system, which corresponds to a memory substitution. On the other hand, the static history path produced the expected consequences that made user more aware of their past actions. The participants took the initiative that it opened up a new field of possibilities (*champs du possible*).

Through these experiments, we were able to explore different design involving different user experience and to understand the technical conditions of a positive experience to task recovering following an interruption. The results are transposable to similar design issues in digital environment.

Finally, since the user' strategy and behavior in visual analysis are similar to those for Tangram problem-solving, we tried to apply this history path concept in a professional analytic application: SAP Analytic Cloud. We designed a mockup with a simple user scenario. We did not have the time for conducting a complete evaluation with business users. However, we presented this mockup to the UX designers with whom we did the exploratory study, and the feedback and suggestions that we obtained from them were quite positive. This mockup needs to be evaluated further with end users.

## 7.2 PERSPECTIVES

By conducting research into enhancing user experience for interacting with analytic applications, this thesis work opens the door to new avenues of investigation; we hope that it could kick-off a follow-up research. There is plenty of future work that can be done. Here

## CONCLUSION AND PERSPECTIVES

we elaborate on some of the limitations of this thesis and corresponding opportunities for future work.

Again, as we have discussed in Chapter 6, the use of Tangram experiment has both benefits and limitations to study the research problem.

We recapitulate the limitations of this experiment in the following:

- The limited number of samples. The results from the second Tangram experiment is not strong enough to have a statistical significance due to the limited number of samples in each group of participants. To further verify our results, we need to recruit more participants. The setting of the experiment could be more precise unless the human variability does not allow to have reliable statistical conclusion.
- The use of the Tangram game for simulating a task of problem-solving does not fully match an analytics task, in which there is no definitive answer. The attitude towards the history path could be different from the Tangram game. The success and failure impact their attitude to the history path in the Tangram game. Then, it is better to conduct an experiment in the context of analytics with the prototype that we have introduced in chapter 7.
- Due to the difference between the Tangram game and a visual analytical task, the participants were engaged in the problem-solving for Tangram, because it is a game. The context of use is different from that of the visual analytical task. Therefore, their motivation may change exploration strategies or willingness to engage.
- Our study captured the participant's first experience with the history path and the results may not be generalizable to long-term use.

Further study will clarify the impact of the history path in a real context. Techniques like the history path should be further developed and evaluated to ensure users have as much cognitive support for an analytical task as possible. We currently lack a precise guideline to discuss their strategies emerged from the use of the history path.

### 7.2.1 A GUIDE FOR DESIGNERS

This thesis work is not about the design of user interface and evaluation of the design. It is more about an opening of design perspective taking the sensorimotor mechanism into account in the design. We have found that this point of view is scarcely adopted in the current design of provenance tool with this view. Through the Tangram experiment, we are able to confirm the possibility of designing a memory supplementation support ("in hand").

The next step would be to establish a guide for conception and evaluation that can be useful for designers. Designing for memory supplementation is a new practice and tools need to be developed to regulate and facilitate the design process. It is thus necessary to allow designers to create such systems and evaluate their effectiveness. How to propose guidelines, recommendations or supports that facilitate the design of mediated user

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interfaces and how the effectiveness of such guides could be measured would be the future work.

## 7.2.2 THE HISTORY PATH FOR COLLABORATIVE WORK

We have reflected on the enhancement of user experience that emerged from the interaction between user and the task mediated by user interface. We focused more on task recovering from the task interruption or suspension by the same user. However, in the context of analytics, the same story or data report often involve two user roles: a data analyst and a consumer. A data analyst is a business user who does data analysis and creates a story or report through data visualization techniques; a consumer is a business user who reads the story or report by sometimes adding some simple operations (filter, sorting, etc.) on it. A consumer is usually a decision maker user type in the SAP analytics user model.

There is a cognitive gap between these two users. A data analyst's work may not be understandable for a consumer. Therefore, the history path framework summarizing the data analyst's work in a more understandable way may benefit the consumer in interpreting the report leading to a more fruitful collaborative work.

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# APPENDIX

## A.1 APPENDIX OF EXPLORATORY STUDY

### A.1.1 INTRODUCTION

This test is a part of my PhD research. As emotional experience is emerged from the interaction with the applications (in BI analytics) (Charles et al. 2007). So, it is necessary to understand under which conditions the applications can provide the interaction which emerges emotional user experience (positive and negative).

We would like to invite you as expert user experience designer to give us your perception or evaluation about 4 different interactive applications. The objective is to find the characteristics of the interaction, which is which is the sensory perception of the interaction between human and application.

The test will be organized in a meeting room. All the participants will interact with 4 applications following scenario script which will be at hand during the test.

Before the experiment, there are some thing to be prepared.

- Please bring your own laptop with your mouse if preferred.
- Download two images in the attachment and put them in your desktop.
- The URLs of 4 different applications:
  - Google Image: <https://www.google.com/imghp>.
  - Airbnb: <https://www.airbnb.com/>.
  - Zero landfill: <http://www.subaru.com/csr/environment.html>.
  - Smart BI : <https://nestledemo-smartbi.dispatcher.neo.ondemand.com/smartbi/hub/>

Other materials will be provided by the test operator.

Erreur ! Utilisez l'onglet Accueil pour appliquer Heading 2 au texte que vous souhaitez faire apparaître ici.

## A.1.2 QUESTIONNAIRE

This is a questionnaire about your profile. Please fill the form and send me by email.

<b>Name:</b>	
<b>Gender:</b>	
<b>Age:</b>	
<b>Educational background</b>	
<b>Current Role:</b>	<input type="checkbox"/> Graphic/Visual design <input type="checkbox"/> Interaction design
<b>Work Experience:</b> (How long have you worked in this role?)	
<b>Preferred Language</b>	
<b>Name 5 applications or website you use most frequently.</b>	
<b>Name 10 adjectives to describe human-computer interaction.</b> (You can refer to the 5 applications you named before)	To be filled during the test
<b>Laptop type</b>	<input type="checkbox"/> Mac book <input type="checkbox"/> Windows
<b>Date:</b>	

### A.1.3 SCENARIO

#### Application 1



**Case A:** use an image downloaded from internet and a screenshot of this image.

1. Search an image in google, type the word “data visualization”, and select one of the images;
2. Save the image and name it ‘data viz’.
3. Open the link of Google Image: <https://www.google.com/imghp>.
4. Drag and drop or import “data viz.jpg” to Google Image to see the result.
5. Capture a screen shot of this image and name it “data viz\_0”, and then save it on the desktop.
6. Drag and drop or import “data viz\_0.jpg” to see the result.

**Case B:** use a photo that is not in the backlog of internet.

1. Import the image “monument.jpg” in Google Image to see the result. (This is a picture I took during the voyage)

**Case C:** Use an image (visualization) that is created in LUMIRA.

1. Import the image “Bubble.jpg” to Google Image and see the result.
2. Add the words “bubble chart” in the input box and see the result.

**Case D:** Play yourself.

Try to explore Google image. You can use the image on the Internet, or you can also use a picture you took, or created.

## Application 2



**Case A:** As Christmas is coming, you want to spend your holiday in London with your family or friend. You need to find an apartment for two days, for example.

1. Open airbnb: <https://www.airbnb.com/> .
2. Type the destination "London" or "londre" based on language setting of your laptop.
3. Select the check in on 12/12/2015 and check out on 13/12/2015, and 2 persons.
4. Click "search".
5. In room type, you want an entire apartment.
6. Select your price range: between 60€ and 100€.
7. Click on "more filters".
8. Click on the drop-down icon in the "Neighborhoods" and select "city of Westminster" and apply filter.
9. Add more filter, you prefer the host can speak French.
10. Browse the results matched with the map on the right.
11. Mouse over one of the result to see the change of the map.
12. Click one of the site in the map to see what happens.

**Case B:** Play yourself.


You can explore other features of Airbnb.

### Application 3

# Zero Landfill

This is a website created by the automobile company Subaru in order to raise awareness of Subaru's environmental history by telling stories. Try to explore the stories.

#### Case A:

1. Open the link: <http://www.subaru.com/csr/environment.html>.
2. Click "Start Exploring".
3. Mouse over to see the change.
4. Hang on year 2014 and click it.
5. Drag and move the line
6. Click on one of the stories.
7. Go to the next one on clicking the "→".
8. Close the dialog.
9. Click ">" in the "< Years >" on the top left and see the change.
10. Click ">" in the "< Month >" on the top left and see the change.
11. Scroll down to observe the change until it returns to form of "the rings of tree".
12. Then scroll up to observe the change.
13. You can also drag the circle  up and down to see the same effect.

**Case B:** Play yourself.

## Application 4



**Case A:** Explore the list of suggestion when typing.

1. Open the link of SmartBI:  
<https://nestledemo-smartbi.dispatcher.neo.ondemand.com/smartbi/hub/>
1. Type "DVD" in the Q&A box, wait a second and enter.
2. Type "DVD sales Revenue 2013 2014 Year", wait and enter.
3. Type "sales revenue DVD year 2013 2014 France" and enter. Observe the results.

**Case B:** Aggregation figures.

1. Type "sales revenue" and enter.
2. Click "Edit results" and select "sales revenue" → "Revenue (€)" → Apply.
3. Return to the Q&A box.
4. Type "sales target" and enter.
5. Click "Edit results" and select "sales target" → "Revenue (€)" → Apply.
6. Return to the Q&A box.
7. Type "sales revenue" and enter.
8. Click "sales revenue" tile and click "compose"
9. Type "sales target" and enter.
10. Drag and drop sales target tile onto the sales revenue tile.
11. Select "Higher is better" (as default normally) and apply.

**Case C:**

1. Type "sales revenue by country" and enter.
2. Click "Edit results" and press "+".
3. Type "sales revenue 2015" and enter.

**Case D:**

1. Type "margin gross by media genre by year" and enter.
2. Click "Edit results" and press "+".
3. Type "sales revenue 2015" and enter.

**Case E:** Create synonyms of keywords.

1. Type "performance" and click "define new keywords".
2. Click "performance" and type "sales revenue / sales target" and then apply.
3. Type "performance" and enter.

**Case F:** Play yourself.

## A.2 APPENDIX OF TANGRAM EXPERIMENT

### A.2.1 INTRODUCTION

Hello, I'm Lingxue YANG, PhD student at the Compiègne University of Technology in User Experience Design at SAP. I am currently conducting my research on the design of re-engaging a problem-solving task to qualify a positive emotional experience.

I would like to do an experiment based on a game called Tangram. Your point of view will be very important for me to better understand these concepts.

This test consists of two sessions: pre-session and post-session. In the pre-session, you will be asked to play a game which is called Tangram to construct a geometric shape for 10 minutes. You will have 2 minutes to familiarize this game. 2 weeks later, you will play the same game again with your history recorded in your pre-session. After the test, you will fill in a short questionnaire and answer questions by watching the recorded video at the end. The post-session will last about 1 hour.

If you agree, both sessions will be recorded via the webcam. During the post-session, your eye movement will be recorded by Tobii Eye tracker as well. The recordings will be anonymous and confidential and be only used for research.

During the test, if you want to take a break, let me know and we'll stop for a moment.



Erreur ! Utilisez l'onglet Accueil pour appliquer Heading 2 au texte que vous souhaitez faire apparaître ici.

## A.2.2 DEMOGRAPHIC SURVEY

<https://lingxueys.typeform.com/to/x5jT3w>

The image shows a screenshot of a Typeform survey titled "DEMOGRAPHIC SURVEY". It contains 10 questions arranged in two columns. Each question is preceded by a number and an arrow (e.g., "1 →").

- 1 → What is your name?\***: Includes a smiley face icon and a text input field with the placeholder "Type your answer here...".
- 2 → What's your gender?\***: Includes a female gender icon and three radio button options: "Male", "Female", and "Other" (with an edit icon).
- 3 → What is your age?\***: Includes a clock icon and six radio button options: "18 to 24", "25 to 34", "35 to 44", "45 to 54", "55 or older", and "I prefer not to answer".
- 4 → In which country were you born?\***: Includes a location pin icon and a text input field with the placeholder "Type or select an option".
- 5 → What is the highest level of education you have completed?\***: Includes a graduation cap icon and five radio button options: "Bachelor's degree", "Master's degree", "Engineering degree", "Professional degree", and "Doctorate degree".
- 6 → What did you study?\***: Includes a book icon and a text input field with the placeholder "Type your answer here...".
- 7 → What is your job title?\***: Includes a person at a computer icon and a text input field with the placeholder "Type your answer here...". Below the field is the instruction "SHIFT + ENTER to make a line break".
- 8 → Which industry do you work in or are most involved with?\***: Includes a dropdown menu with the placeholder "Type or select an option".
- 9 → Which kind of software do you mainly use for your work?\***: Includes a computer monitor icon and a text input field with the placeholder "Type your answer here...".
- 10 → What was your strategy for playing this game?\***: Includes a lightbulb icon and a text input field with the placeholder "Type your answer here...". Below the field is the instruction "SHIFT + ENTER to make a line break" and a blue "OK" button with a checkmark and the text "press ENTER".

## A.2.3 SEMANTIC EVALUATION

For both static and dynamic history path

<https://lingxueys.typeform.com/to/MIVPed>

## APPENDIX

- 1 → The following word pairs will help you for your assessment. They represent stark contrasts and can be subdivided into further rating levels. For example:

This rating indicates that the product is quite pleasant but has room for improvement. Do not ponder over the word pairs and make your assessment spontaneously. You may feel that some word pairs do not fit the product very well. However, we would ask you to give an answer anyway. Remember that there are no "right" or "wrong" answers - your personal opinion is what counts.

Agréable                      Désagréable

1      2      3      4      5

- 2 → With the help of the word pairs please enter what you consider the most appropriate description for **History Path** feature you had during the test session. Please click one item in every line.

a. Compréhensible                      Confus

1      2      3      4      5

e. Déroutant                      Assisté

1      2      3      4      5

b. Intuitif                      Non-Intuitif

1      2      3      4      5

f. Utile                      Inutile

1      2      3      4      5

c. Ennuyeux                      Amusant

1      2      3      4      5

g. Désagréable                      Agréable

1      2      3      4      5

d. Cohérent                      Incohérent

1      2      3      4      5

h. Originale                      Classique

1      2      3      4      5

### A.2.4 EXPERIENCE MAP

Erreur ! Utilisez l'onglet Accueil pour appliquer Heading 2 au texte que vous souhaitez faire apparaître ici.

Experience map for participants who failed the first time and succeeded the second time with **dynamic** history path

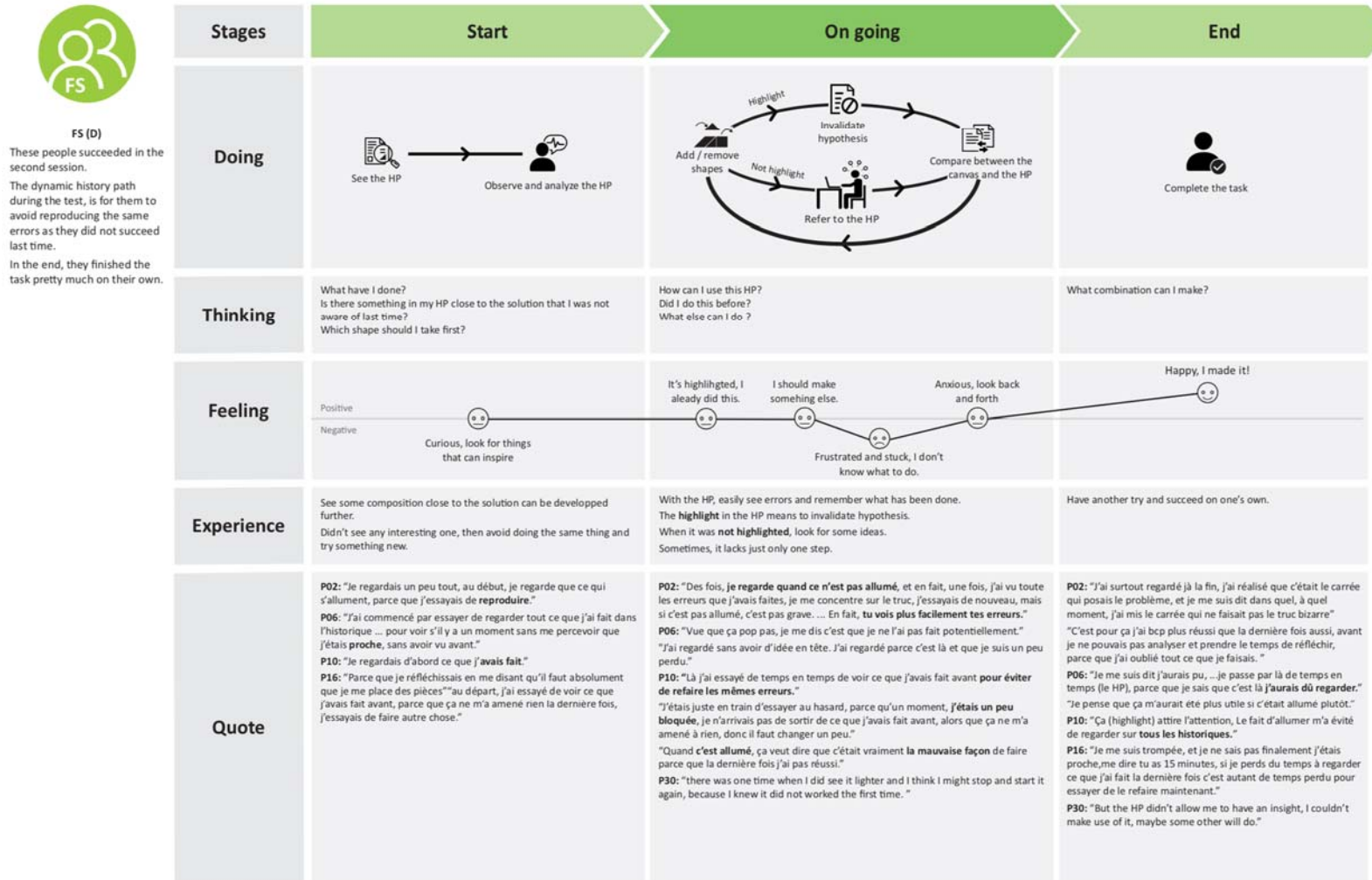


Figure 50. Experience map for FS (D)

Experience map for participants who failed the first time and succeeded the second time with **static** history path



**FS (S)**  
 These people succeeded in the second session. The static history path during the test, is for them to both avoid and refer. They are more actively searching for the information instead of being received passively as in the dynamic history path.. In the end, they finished by finding key path in the HP which unblocked their difficulty.

Stages	Start	On going	End
<b>Doing</b>	See the HP →  Observe and analyze the HP		Realize the blocked shape →  Complete the task
<b>Thinking</b>	Is there something in my HP close to the solution that I was not aware of last time? What did not work?	Did I do this before? Can I do something based on these two or three shapes? What else can I do ?	I find this match what I am thinking, maybe I can have a try. I realized that I always did the same thing.
<b>Feeling</b>	Positive:  Negative: Look for things that can inspire	OK, I already did it.  With these shapes, can it work?  Frustrated and stuck, I don't know what to do with it.  Anxious, look back and forth.	Glad, unblocked.  Happy, I made it!
<b>Experience</b>	Notice something interesting to reproduce. See the history as the errors that have been done, then do not repeat them.	Compare between the canvas and the HP to avoid doing the same. The HP altogether helped for inspiration. When return to the task, you start very quickly to redo the same forms.	Focus on one area in the HP which unblock the problem and combine it with the current strategy.
<b>Quote</b>	<p><b>P07:</b> "J'essayais de voir s'il y a des formes que je peux reproduire et voir si j'étais si avancé, là donc ça, ce sont les erreurs que j'avais faites qui me n'ont pas aidé à avancer, donc j'essayais d'éviter de placer les éléments au même endroit pour pouvoir proposer d'autre ajustement."</p> <p><b>P17:</b> "Voilà j'ai regardé pas mal de HP, parce que la première fois j'ai pas du tout réussi à le faire ce triangle, donc, j'ai cherché un peu qu'est-ce qui n'est pas marché. Donc, je me sentais déjà moins perdu."</p> <p><b>P18:</b> "J'essaie de voir si qu'il m'a fait le plus proche d'une solution, c'est pour ça, j'ai fixé pas mal de ce truc-là."</p> <p><b>P19:</b> "En fait, là je regarde le résultat, je me dis, à quelle distance j'étais du résultat"</p> <p><b>P25:</b> "I just wanted to look for from my HP where the things were closest to the solution, which part should be the right angle. I didn't act, because I was analyzing it."</p> <p><b>P31:</b> "Je regarde rapidement pour voir où est-ce que j'avais utilisé la forme avant en premier pour ne pas reproduire la même chose."</p>	<p><b>P07:</b> "Parce que j'ai passé bcp de temps sur ça au début de mémoire. Surtout cette partie-là est basée sur le carré qui s'est planté, donc, je pense que les autres tentatives aussi mais pas aussi réussies."</p> <p><b>P17:</b> "Je revoyais au début juste voir s'il y a d'autre chose qui peut m'inspirer."</p> <p>"C'est le carré qui m'embête. Mais Je cherche comment continuer avec les exemples au-dessus. Je suis désespérée."</p> <p>"Je compare pour voir ce que j'ai déjà fait la dernière fois, si ça n'a pas marché, quelque fois, je me rends compte que je suis en train de reproduire de qui a été fait au-dessus, donc je sais que ça ne marche pas, donc j'érêve ce que j'ai déjà fait. "</p> <p>"Je suis perdu mais je regarde partout pour trouver un modèle qui pourrait m'aider."</p> <p><b>P18:</b> "Voilà là, je me dis que cet assemblage est déjà fait, j'ai déjà galéré là-dessus. Le HP commence à me travailler je pense."</p> <p>"... Voilà désespoir sur le carré. Je ne sais pas quoi faire."</p> <p><b>P19:</b> "Si, je regarde le HP, mais ça fait partie de ma stratégie, c'est cohérent. Là, je suis encore en train de m'inspirer peut-être de ce que j'ai. "</p> <p>"Je suis un peu désespéré. Je suis incapable de me dire si je vais résoudre ou pas."</p> <p>"Par là négative me dire, refaire pas la même erreur que le passé"</p> <p><b>P25:</b> "I was looking for some inspiration."</p> <p>"... ça me même si j'ai réessayé la même chose qui avait été faites, ça faisait comme confirmer que ça ne marchera pas."</p> <p><b>P31:</b> "C'est vraiment plus je m'en suis vraiment servi en me disant de toute façon, je n'ai pas réussi la dernière fois, c'est plutôt pas recommencer forcément la même chose. "</p>	<p><b>P07:</b> "Le HP m'a montré les erreurs du passé et essayé de débloquent sur le carré bleu en fait."</p> <p><b>P17:</b> "En fait, c'est ce que je me suis dit au moment j'ai changé de stratégie..."</p> <p>"Ça faisait comme confirmer que ça ne marchera pas, et puis même psychologiquement je pense que ça m'aide d'avoir des autres exemples, même si c'est pas bon, je me sens moins seul avec mon petit truc."</p> <p><b>P18:</b> ". Justement, regarder dans le HP celui-là je vois que j'ai réussi à rentrer le carré et avec le gros triangle orange dans la forme. Et du coup, en assemblant ça avec l'assemblage que j'avais avant entre le triangle et le parallélogramme. Du coup j'arrive à la solution-là."</p> <p>"Ce qui est intéressant c'est je fini par me référer à HP, ... ça me développe en fait."</p> <p><b>P19:</b> "Je vais le mettre à horizontal, tiens, essaie là, je n'ai pas fait dans mon historique."</p> <p><b>P25:</b> "I learned from the HP, I was thinking the big triangle to be the right angle of the triangle, especially this part."</p> <p><b>P31:</b> "Surtout je me suis rendu compte, grâce au HP, j'avais tourné jamais celle-là, je me suis dit peut-être que je peux creuser."</p> <p>"J'étais mieux guidé, c'est-à-dire que je suis vraiment dans les essais pertinents grâce à mon HP encore une fois."</p>

Figure 51. Experience map for FS (S)

Erreur ! Utilisez l'onglet Accueil pour appliquer Heading 2 au texte que vous souhaitez faire apparaître ici.

Experience map for participants who failed the first and the second time with **dynamic history path**

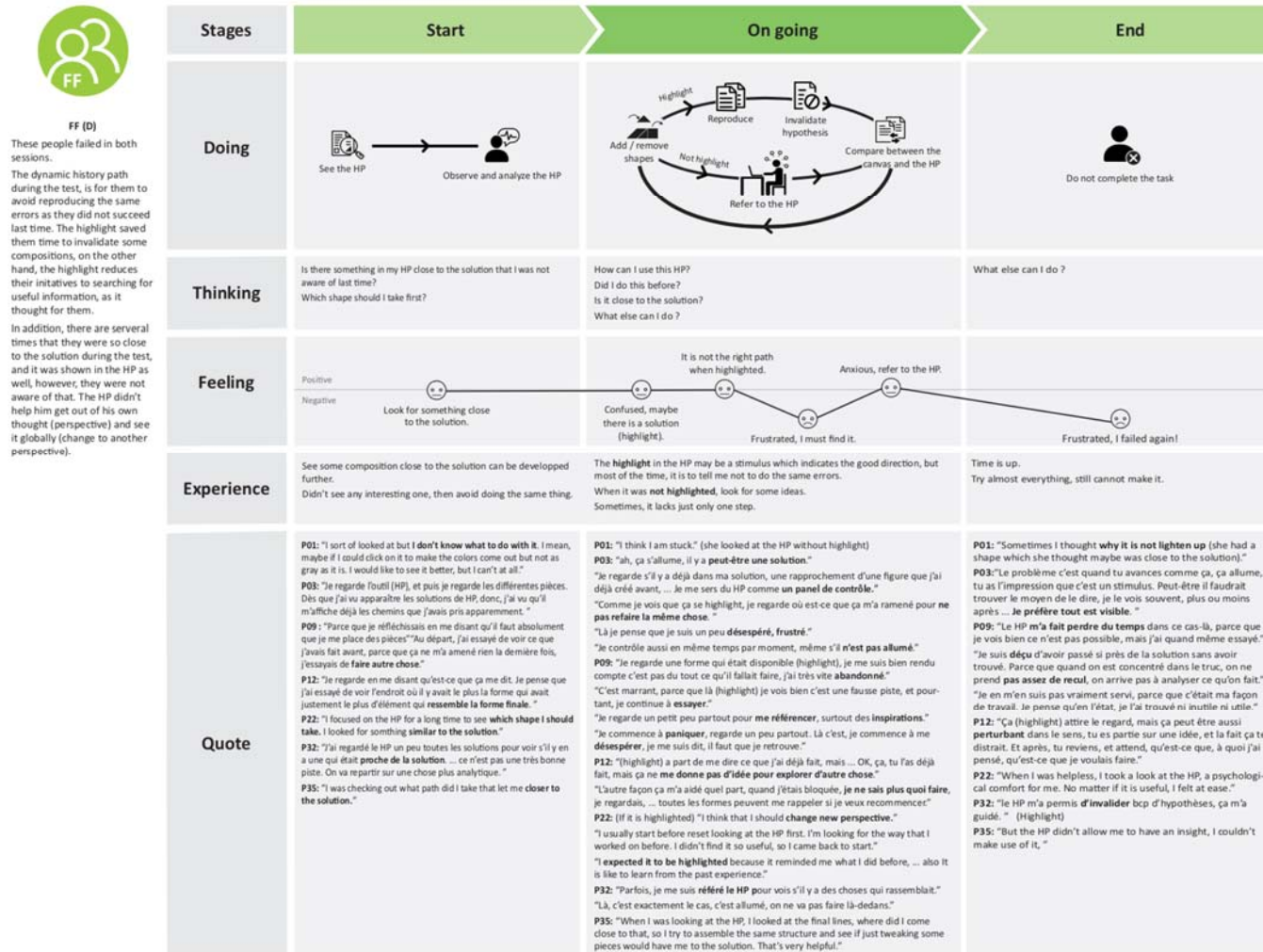


Figure 52. Experience map for FF (D)

Experience map for participants who failed the first and the second time with static history path



**FF (5)**  
 These people failed in both sessions.  
 The static history path during the test, is for them to both avoid and refer. They are more actively searching for the information instead of being received passively as in the dynamic history path.  
 However, there are several times that they were so close to the solution during the test, and it was shown in the HP as well, however, they were not aware of that. The HP didn't help him get out of his own thought (perspective) and see it globally (change to another perspective).

Stages	Start	On going	End
<b>Doing</b>	→		
<b>Thinking</b>	Is there something in my HP close to the solution that I was not aware of last time? What did not work?	What did I do before? Does it work? What else can I do? It always lacks a shape.	What else can I do ?
<b>Feeling</b>	Positive Negative	<p>I might be close to the solution, but it lacks a shape.      Anxious, look back and forth.</p> <p>Don't do the same thing.      Frustrated and stuck, I don't know what to do with it.</p>	Frustrated, I failed again!
<b>Experience</b>	The HP showed me what I have done. I realized that I always put this shape in on n edirection. Nothing is close to a triangle, avoiding doing this.	Compare between the canvas and the HP to avoid doing the same. The HP altogether helped for inspiration. Several time close to the solution, but was not aware of that.	Time is up. Try almost everything, still cannot make it.
<b>Quote</b>	<p><b>P14:</b> "Au début, j'ai pas trop regardé, je me suis dit que je vais réfléchir. Après, je regarde, j'essaie de chercher des exemples qui pouvaient être <b>assemblés</b>. J'ai regardé que l'orange pouvait assembler avec la rose, l'orange ne pouvait pas assembler avec le carré, par exemple. C'est ce que je cherche au début."</p> <p><b>P15:</b> "J'étais en train d'essayer de voir si ce que j'avais fait avant <b>ça a marché</b>."</p> <p><b>P23:</b> "I looked at the HP to see if there was something <b>close to the solutions</b>. The HP is visual."                      "At first, I <b>analyzed</b> my process of doing it last time. For example, this is totally impossible, how did I do that last time?"</p> <p><b>P24:</b> "J'ai essayé de voir parmi tout ce que j'avais déjà fait, s'il y avait quelque chose qui <b>ressemble</b>."</p> <p><b>P27:</b> "Décider plutôt pour voir s'il y avait quelque forme classique qui rajoute, décidé à ce que j'avais en tête."</p>	<p><b>P14:</b> "De temps en temps <b>quand j'étais proche</b>, j'ai essayé de le rechercher un petit peut, j'ai essayé de les utiliser, bon il faut que j'arrive à l'utiliser."                      "Là, je me suis fixé, le carré et la rose, c'est pour ça je regardais le carré et la rose dans le HP, j'ai vu j'avais fait pareil en fait. Je me suis dit, comment de là on peut arriver à s'en sortir. J'ai vu que je n'avais pas mis l'orange, j'ai essayé de le mettre."  <b>P15:</b> "Et là, je me suis dit, si je recommence par-là (un endroit dans le HP). Je regarde si ... si je n'étais pas loin pour réussir. Au lieu de prendre le triangle en haut-là j'avais mis, <b>j'essaie autre chose</b>."                      "Je <b>compare</b> pour voir ce que j'ai déjà fait la dernière fois, si ça n'a pas marché, quelque fois, je me rends compte que je suis en train de reproduire de qui a été fait au-dessus, donc je sais que ça ne marche pas, donc j'enlève ce que j'ai déjà fait."  <b>P23:</b> "Because last time, I didn't succeed, then I thought <b>doing something different</b>." "I always think that there lacks a shape." "I was looking for <b>inspiration</b> as I tried many times in vain."  <b>P24:</b> "Là, le HP m'a servi pour essayer de <b>ne pas refaire la même chose</b>. ... Mais parfois je regarde quand même s'il n'y a pas un step deux ou trois quelque chose intéressante, parfois j'allais quand même regarder cette ligne-là."                      "Parmi tous mes essais, c'est ce qui se rapproche le plus, mais il <b>manque une pièce</b>."                      "Je suis <b>coincé</b>. Je n'ai plus d'idée là. Je ne retiens pas forcément dans ma tête ce que j'ai fait avant. Là, je suis en train de regarder un par un. Je cherchais comment mettre le carré et comment mettre le parallélogramme."  <b>P27:</b> "J'ai cherché des différent permutations que <b>je n'avais pas essayé avant</b>, cette méthode, j'ai essayé d'explorer les autres possibilités à partir du HP, mais ça ne m'inspirait à rien."</p>	<p><b>P14:</b> "Ça ne te donne pas dans le chemin, ça te dit pas si c'est plus ou moins, si tu es dans la bonne direction ou pas, ça te donne juste des erreurs que j'avais fait."                      "Ça te dit, tous été fait pas bien placé, mais <b>ça ne te dit pas qu'est-ce qu'il faudrait, comment il faudrait faire, en fait</b>."  <b>P15:</b> "Ça ne me sert pas grande chose, si ça ne me dit pas là tu t'es rapprochée plus que là."  <b>P23:</b> "The HP is visual for you to see what you have done easily. But I still don't find the solution."  <b>P24:</b> "Je me suis fait une réflexion, je n'ai jamais démarré avec ce violet-là ... j'ai tenté la nouvelle chose (grâce au HP)."  <b>P27:</b> "Je me suis obligé presque à pas regarder pour rester fraîche."</p>

Figure 53. Experience map for FF (S)