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## A Design Model for Tangible Interaction: Case Study in Waste Sorting

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**Abstract:** In this paper, we propose a design model for applications with Tangible User Interfaces (TUI). This model aims to support designers in organizing the different elements and their relationships. We then implement the model through the design of a Serious Game for an RFID tabletop that uses tangible objects: this Serious Game simulates microbiological waste sorting in a practical educational setting. In this case study, a scenario is described, highlighting the use of the design model. The conclusions and suggestions for future research are then presented.

*Keywords:* TUI Design Model; Tabletop; Tangible object; Serious Game; RFID; Waste sorting

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### 1. INTRODUCTION

Shneiderman (1983) says the following about video games: “perhaps the most exciting, well-engineered - certainly, the most successful - application of direct manipulation is in the world of video games”. With improvements in technology, inputs and outputs are getting closer, enhancing the feeling of direct manipulation (e.g. touch, stylus, movements). One of the emerging technologies that fosters this enhanced closeness involves Tangible User Interfaces (TUIs) (Ishii & Ullmer, 1997). TUIs allow interaction to take place with a virtual application through real objects that can represent application data (see the definition of (Hornecker, 2005)). And finally, to become closer, inputs and outputs have merged (Ullmer & Ishii, 2000).

In the video games field, we can refer to *Activision Skylanders* released in 2011. In this game, one or more real figurines are selected and placed on a base. A playable avatar of one or more figurines appears in the virtual world via the TV screen. We can also mention the STARS platform (Magerkurth et al., 2004) to generate games for tangible and tactile tabletops. This platform aims to emulate board games, enhancing them by adding a virtual layer (sound, a screen-based game board equivalent, a vertical screen for general data and Personal Digital Assistants for private data). In this case, a player directly interacts with a figurine and moves it.

The question that subsequently arises is: how to design a TUI application taking into account every physical or digital element? In order to clarify this point, we propose in this paper a design model which takes into account the different elements we can find with TUI as well as their relationships.

After identifying what kind of video toys considered as TUIs exist on the market, we will present several HCI models in Section 2. From these models, we propose a design model for tangible interaction described in Section 3. A case study showing the development of a Serious Game on a TUI is then

presented in Section 4. The implementation of the serious game is presented in Section 5 in a scenario illustrating the model. The article ends with a conclusion and suggestions for future research.

### 2. STATE OF THE ART

To begin our study, we first considered video toys currently available on the video game market; they are for us a source of ideas for designing new types of industrial or educative applications. We then studied several HCI models that could be compared with each other to create a model for designing TUI applications.

#### 2.1 Video Toys as Tangible Objects

By video toy we mean one or more physical elements, such as figurines, linked to at least one digital application. This link augments the figurine, giving it a life, capacities, and so on.

Activision launched the first successful toy of this kind in 2011. It is *Skylanders: Spyro's Adventure* game. The digital character you play corresponds to the physical figurine placed on the base and linked to the game console. Similarly, in 2013 *Pokemon Rumble U* by Ambrella uses the NFC component of the Wii U game console to incorporate figurines. Placing a *Pokemon* figurine on the GamePad allows the player to use this *Pokemon* in the game. The *Pokemon* and *Skylanders* figurine characteristics, which evolve throughout the game, are stored in the figurines. A similar game released by Avalanche Software in 2013 is *Disney Infinity*. It uses trophy and disc objects to enhance the current character's abilities. These discs can be superimposed and the character figurine can be placed on top. More recently, we can cite *Nintendo Amiibo* figurines which are available since late 2014. All these physical toys are physical avatars, behaving like an ID card. Once a figurine is placed

on the base, users no longer need to interact with them and can play using pads and screens.

Prodigy by Hanakai Studio is a game developed in 2015. It works with figurines, a base and cards. The base is linked to a computer. It is a tactical game. Contrary to previous games, in this one, players interact with physical elements. The users can strategically place their figurines in different squares on the base. Putting a card on the base allows a figurine to perform a specific action that will be digitally represented (through the screen). Here, the digital layer augments the real situation, adding a fantasy layer to the game and making the characters seem alive. On tablet (iPad), the version of Cars 2 developed by Avalanche Software in 2011 allows controlling a physical small car called appMATES, while the screen of the iPad displays the landscape for the race. The car is placed directly on the iPad and allows the user to control the direction taken. Thus, the object is directly immersed in the virtual world. Finally, the ePawn company (2010) was able to develop video toys using its Arena surface (2012) and tracking technology. As for the Cars 2 iPad application, physical elements are detected and immersed. Several elements can be detected at the same time, and mobile elements can even be linked to the surface.

By analyzing these games, we can observe three ways of using a digital layer with physical objects: (1) A physical object enables an avatar with associated stored data to be selected. Then, all happens digitally. (2) The physical object is used to play. But to endow it with a life, movement, abilities and things that cannot be provided physically (or in a very complex way), a digital layer is used. This layer augments the object, or the image we have of it. (3) The physical object is immersed in a digital environment. One would not function without the other. The digital layer brings meaning to the game (for example, the road and obstacles), and the physical elements must respect this meaning. More than augmenting the object with effects, the digital part forms the structure. This notion of structure can be applied to a set of objects as in Disney Infinity application. The discs, alone, don't have any sense. But with a figurine, it increases one of its ability. The figure is a part of structure for the disc.

This section deals with objects that represent the targeted element with which the user wants to interact. But sometimes, objects in augmented reality are tools, intermediaries between the user and the targeted object. This is what is explained in the next section.

## 2.2 Domain Object and Interaction Instrument

Beaudouin-Lafon (2000) says that "Our interaction with the physical world is governed by our use of tools". He defines then what he calls domain objects and interaction instruments. The domain objects are directly linked to the aim of the task; they are "objects of interest", whereas interaction instruments are intermediaries used to perform the task and to interact with the objects of interest.

The AppMATES car from the Cars 2 application is a domain object, as it is the object of interest in this racing game. In

contrast, the application introduced by Fitzmaurice et al. (1995) uses tangible bricks to manipulate digital forms. In this case, the bricks are interaction instruments. If we refer to Ishii and Ullmer works (2012), we can tell that physical domain objects are linked to digital information and physical interaction instruments are linked to computational function.

Beaudouin-Lafon stipulates that depending on the task to be performed and the user's focus, an interaction instrument can turn into a domain object. He gives the example of a pencil, which is actually an instrument for writing text. The pencil becomes an object of interest when the user needs to sharpen it; the pencil sharpener is the interaction instrument.

To go further in the analysis of the relation between the physical and the digital layers, we refer to the notion of feedback: how a user can glean information from his/her experience through digital and physical interactions.

## 2.3 Tangible User Interfaces and Feedback

Ishii and Ullmer (2012) explain that three feedback loops exist in this field. The first loop involves immediate tactile feedback received by the user when he/she manipulates an object. It is a passive feedback felt by the user, for example, when moving the object, changing its direction or putting it on the table. This feedback allows the user to note the new state of the object through his/her haptic perception. The second feedback loop pertains to what the user perceives from the digital device. The system's state is updated according to the new state of the object(s); this update is directly communicated to the user through digital information (the feedback could be visual or audio). It concerns all non-tactile feedback. The third kind of feedback loop involves an updating of the object without user intervention. In the model presented in (Ishii & Ullmer, 2012), the computer actuates the object (the object can then modify its appearance or move by itself). For example, we observe that, in this era of smart objects, the object can update itself with contextual changes.

Thus, there are three feedback loops to take into account when designing a TUI application: (1) sensory feedback linked to the object, (2) digital feedback linked to the application and (3) actuation feedback of the object by itself or by the application. The two first loops are the loops experienced most frequently when using TUIs. They are even considered as essential in Ishii's and Ullmer's opinion in Tangible Interaction.

## 2.4 The Execution and the Evaluation Phases

We can refer to the Norman's action cycle (Norman, 2002) to understand when the previously studied feedback loops can be exploited.

There are four elements to consider in Norman's model: (1) the goal of the user, (2) the execution phase (i.e., what the user does to achieve his/her goal), (3) the world and (4) the evaluation phase (i.e., when the user perceives the world and compares it to his/her expectations). The execution phase is divided into three stages: (1) the intention (by what means

does the user want to achieve his/her goal), (2) the sequence of actions to perform to fulfill the intention and (3) the execution stage, when actions are performed, changing the state of the world. Then, the evaluation phase is divided into three stages. During the first one, the user perceives the world. Then, he/she interprets the perceived world according to his/her expectations and finally, the user compares this with his/her initial goal as well as with the intention chosen to achieve the goal. Has the goal been achieved? Was it achieved as desired?

Going back to the augmented reality field, Dubois et al. (1999) refer to the Action Theory of Norman to show that two types of augmentation exist: during the execution phase and during the evaluation phase. Let us use the work by Pedersen et al. (2011) to illustrate this theory via the less well-known object actuation feedback loop. Augmentation during the execution phase means that a digital layer is added to accompany the user throughout this phase. This corresponds to the interaction commands terms used by (Pedersen & Hornbæk, 2011); the imitation is proposed as an example. The user records movement for some objects, one by one. These movements can then be replayed simultaneously thanks to a command. This is of interest when the number of objects to manipulate simultaneously is superior to the number of available hands. Augmentation in the evaluation phase helps a user execute his/her evaluation phase by adding some digital information to the real world. In the work of Pedersen & Hornbæk (2011) the used words are *interaction feedback*. One of the proposed examples is to create resistance when turning an object used to modify a value on a scale when the user approaches one of the end points of the scale (like when increasing sound volume).

We saw that three feedback loops can be used during the execution and evaluation phases: sensory feedback, augmented sensory feedback and augmented digital feedback. These feedback loops are part of the user experience, and it is necessary to take them into account when designing an interactive application. Whether real world or virtual world, users act on tokens and the observable results of these actions allow them to evolve and appreciate the experience. Let us see how the various feedback loops and their functioning can be taken into account for the design of applications incorporating virtuality and tangibility.

### 3. PROPOSAL: A DESIGN MODEL FOR TANGIBLE INTERACTION

This section presents our model proposal. Its purpose is to show how to consider every element together when designing a digitally augmented application. We took into account the different data we collected through previous models and video toys analysis. The model is represented by the Fig. 1.

We share previously studied elements into two categories: physical and digital. A physical object represents at least one digital element: a computational function, digital information and/or a scenery. Function of what it represents, this physical object can be specified as being an Avatar Object, a Domain object or an Interaction Instrument. But this specification does not always apply. Indeed, we want to consider all

devices of the system including interactive surfaces for example. Each object, whether physical or digital can structure other objects, giving them constraints, indicating ways of using them (Ullmer et al., 2003).

Existing elements must have related to the user(s)' goal(s). The best we know the different goal of the user, the best we can give him or her feedbacks to help in the evaluation or execution phase as defined in Norman's action cycle. We integrate then the three feedback loops described by Ishii's and Ullmer's. The two feedback loops concerning the haptic field are gathered with the *Haptic Feedback* class. The last feedback loop concerning the other fields (e.g. audio, visual) is represented by the *Digital Feedback* class. These classes are association classes. Indeed, in this situation a feedback cannot exist without an action of the user on an element of the system.

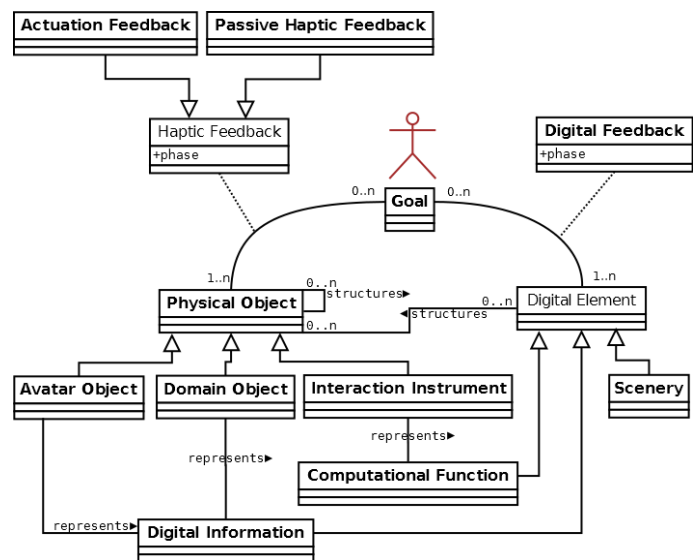


Fig. 1. The proposed Design Model for Tangible Interaction

#### 3.1 How to use the model

First of all, goals have to be defined. Then, each physical object and digital element which can be manipulated has to be connected to a user goal. When these elements are manipulated, the user will receive one or several feedbacks in relation with his/her action, improving interactivity. The feedback can help him/her in the execution phase (manipulating the object), the evaluation phase (interpreting the results of his/her action) or even both phases.

Each physical object must be linked to at least one digital element it represents. It can be whether a digital information (a data from the model) or a computational function (which controls a digital information). For example, the “Zoom object” of the road traffic simulation application presented in (Lebrun et al., 2015) represents the control of the display scale. The model and the object are illustrated in Fig.2.

A physical object can be constrained by one or several other physical and/or digital elements. These elements create a structure for the physical object to be manipulated. The model encourages defining this relation.

To test this proposal, we implemented it in the context of a Serious Game that aims to teach microbiology students to properly sort their waste during practical exercises.

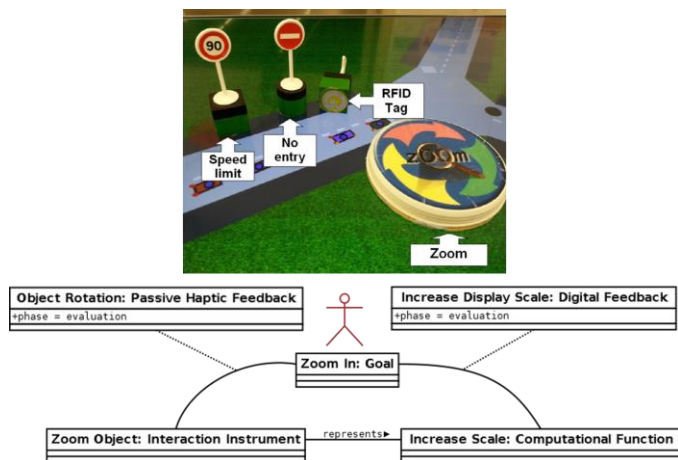


Fig. 2. Traffic simulation application objects (above); our model proposal applied to the *Zoom* object (below).

#### 4. IMPLEMENTATION: SERIOUS GAME ABOUT WASTE SORTING

In this section, we present a Serious Game about waste sorting on the interactive tabletop *TangiSense*. It is implemented using the proposed design model for tangible interaction. Game concept story, equipment used and gameplay are successively described.

##### 4.1 Game Concept Story

University of Littoral Côte d'Opale (ULCO), located in the North of France, incorporates microbiology into almost all courses of study from first-year university level to the Masters degree level in the Department of Life Sciences and Nature. For many years, the university has been welcoming non-french speaking students for whom the domain-specific vocabulary is difficult to master as they learn the language. Furthermore, for health reasons (e.g., disability, serious illness, pregnancy), it is sometimes difficult or impossible for some students to attend practical sessions (use of dangerous products). In another context, people who wish to receive professionalized training need to boost their general microbiology knowledge. Several issues emerge: problems of accessibility for foreign students due to limited vocabulary, problems of improving for beginners and problems of practical facility accessibility.

In order to develop necessary best practice in microbiology knowledge, the university decided to integrate Serious Games that are accessible outside of the practical setting into different learning modules. These games are likely to be more attractive (Abt, 1970) than a traditional educational medium (e.g., textbook, e-learning). Physical handling is essential in this area, which is why maintaining this physical appearance seemed important. We decided to use the tangibility of a tabletop, which, in the future, may represent the laboratory bench top for other applications. We also took into account the laterality of the user: indeed, during

manipulation in a laboratory, the arms of the different users should never cross, or accidents could occur.

The first module on which we focused is the sorting of waste and materials in a practical work session. In addition to addressing the aforementioned problems, this module caters to more specific issues identified during the practical sessions: students do not distinguish between types of waste (household, biological, glass), they confuse contaminated waste with uncontaminated waste, they do not dare ask for help from an assistant or an educator, they do not take the time to sort waste at the end of the session and they do not necessarily separate liquid media from solid media, which has repercussions when sterilizing containers in an autoclave. In an autoclave, solid media will melt during sterilization, becoming liquid, but will harden again during cooling. People in charge of disposing of the contents of each container may confuse media.

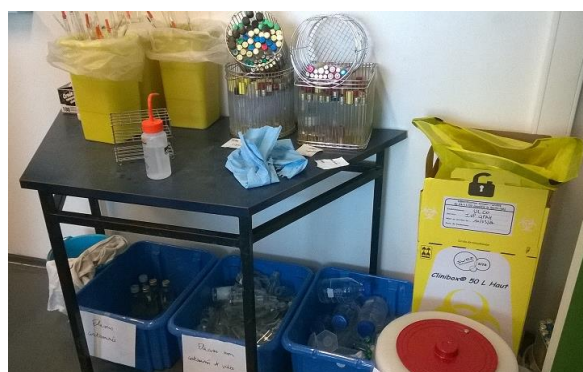


Fig. 3. Collection containers, photo taken during a practical session

After the needs analysis and practical session observations (Fig. 3 shows how the collection containers are placed in practical sessions; note that we only present the collection containers to be used by students), we organized elements into three categories: container type, contents type and associated contamination risk. These are the three categories that let you know which collection container will be appropriate. If a category is not specified, it means that it is not necessary for sorting the waste in question. We should specify that for pipettes, it is necessary to soak the dirtied part in bleach for at least seven minutes before placing it in the collection container.

##### 4.2 Equipment

The game is developed for the *TangiSense* tabletop. This interactive tabletop is equipped with RFID technology for manipulating tangible and traceable objects. It is designed by the RFIdees company. These objects are equipped with one or more RFID tags that are automatically identified and located by the drive array comprising the interactive tabletop. The table is equipped with a Full HD 47-inch screen display to immerse the user in a universe both real through tangible objects and virtual through the screen. The architecture used is the one proposed by Kubicki et al. (2009). It uses several layers: (1) the application layer involving a multi-agent

system that links each tangible object to a software agent (see (Kubicki et al., 2013) and (ISO, 2010) for more descriptions), (2) the traceability layer for detecting the position of objects and launching the associated events, and (3) the capture and user interface layer, capturing the presence or absence of objects and creating virtual agents.

### 4.3 Gameplay

The goal of this serious game is to successfully combine waste with its appropriate waste collection container. The play area consists of a grid on which collection containers appear randomly one by one. The area also contains a zone with the score and the representation of bleach in which the contaminated pipettes need to be soaked, and an information zone in the event that the user needs help. The position of this zone adapts to the lateral dominance of the user defined by his/her avatar object. Once the objects are associated with a collection container, it is impossible to reuse them for the current game; they are considered discarded. The collection container display and the score are then updated according to the sorting. Each user has an avatar object which permits to know his/her laterality and his/her best score.

We opted for positive scoring: only correct actions earn points. We integrated the combo concept to benefit consecutive correct choices made without using the combo increases by one. The score increases by the value of the combo. The combo is reset when a bad choice is made, when incorrect sorting has taken place or when the information zone is used. The score display changes color with the value of the combo.

The information zone, which moves functions of player's laterality (stored with the avatar object), allows the player to obtain clues about an object that has not yet been discarded. The object must therefore be put on the zone representing a microscope so that the representation of its screen provides one of the following clues, depending on the object: (1) it is biologically contaminated or (2) it is considered to be sharp or pointed or (3) it has a chemical risk or (4) it is recyclable or (5) it is safe.

The collection containers defined above randomly appear for T time, T depending on the game level, in a 3x4 grid. If no waste has been placed in the current collection container, it fades after t seconds. If waste is placed in it, the collection container remains apparent and two other elements appear to assist the user during the evaluation phase; an icon, in the bottom right corner of the square, lets the user immediately know whether or not the sort is correct or not. In addition, in the event of error, a visual element placed above the collection container lets the user know why the sorting has been incorrectly performed: chemical contamination, bacterial contamination, or inadequate sorting (which will imply issues in organization or loss of money). A collection container can receive only one waste item. A given collection container can appear more than once.

The presence of bleach is situated above the information zone to simulate the bleach's position on the lab bench. A pipette

that is not dipped in bleach before being discarded bacteriologically contaminates the selected collection container, even if it is the pipette collection container. On this zone a pot is placed, the same as the one we can find during practical work sessions to make users understand what this zone is for. After seven virtual minutes in the bleach zone, the object in the zone adopts the bleached state, thereby increasing the score if the action is useful. Otherwise the value of the combo is reset to zero.

## 5. SCENARIO ILLUSTRATING THE PROPOSED MODEL

As mentioned before, a contaminated pipette has to be soaked in bleach before being put in the collection container. This is this part of the game we will use in this section. First, the goal of the user is to place the pipette in the pot representing bleach (Fig. 4). The pot was previously placed on the “bleach zone”; a scenery representing the bleach. The pot gives a structure to the pipette when placed into it and indicates to the user how to place the pipette. It helps the user in the execution phase. When the pipette is placed in the pot the bleach scenery highlights. The model of this action is illustrated in Fig. 4.

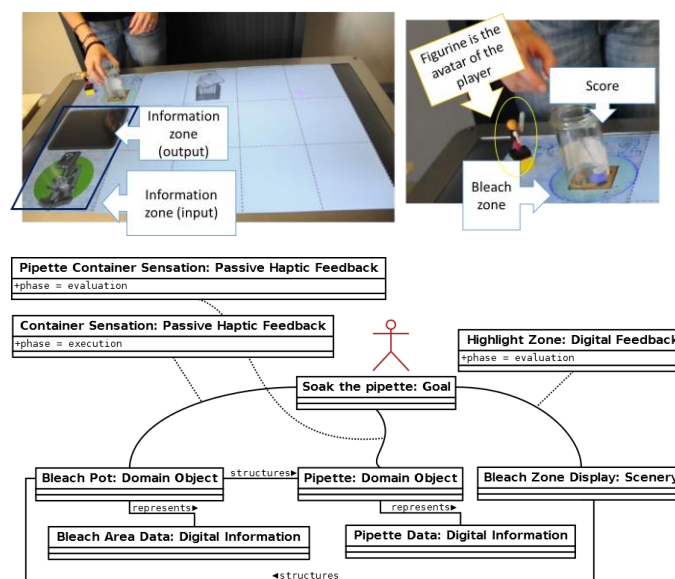


Fig. 4. “Soak the pipette” action (above); “Soak the pipette” model (below).

Then the user has to wait for seven “virtual” minutes (faster than in reality). After what our project is to make the pot vibrate as an alarm-clock (cf. centre of Fig. 5). The goal for the user is to know that the pipette is ready to be discarded. To finish, when the correct collection container appears, the user discards the pipette putting it on the display of the container (cf. Figure 5 - right). The container appearance changes functions of the sorting result. We have chosen to illustrate a part of scenario with the three types of feedbacks; more illustrations and models are available but cannot be integrated in this section because of lack of space.

The process followed during the design of this game is shown on Fig 6.



Fig. 5. Left and center: “The pipette is ready to be discarded”. Right: “Discard the pipette”.

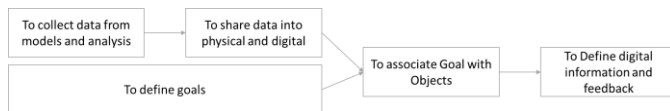


Fig. 6. Actual design process used to establish the model.

## 6. CONCLUSION

The concept of feedback is very important when interacting in digital mode or in the real world (Ishii & Ullmer, 2012). Feedback allows a user to understand, learn and evolve from his/her actions. This is why the proposed Design Model for Tangible Interaction associates each component to a user's goal through feedbacks. Feedbacks can happen during evaluation and/or execution phases. The relationship between objects is also present: in the physical world, every physical element is delimited by other physical elements and this fact must be taken into account. It represents the space. We put this model into practice through a Serious Game dedicated to learning how to sort waste during a practical microbiology work session (evaluation from the design point of view). We illustrated this application in relation to the proposed model with a scenario. We are currently organizing an evaluation with users (evaluation from the learning point of view). For future research, we should consider applications with several users collaborating around the same tangible tabletop and/or collaborating remotely (Pauchet, et al., 2007; Bouabid et al., 2014) in order to validate the design model in several contexts.

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