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Coupling of Serendipity, Affordance and Taxonomy in Digital Competence: HCI for Illiterates

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Abstract

This research work is the result of multidisciplinary research for the design of a digital learning tool from the basic level. Computer science guarantees the technical concepts of the development of the tool. At the same time, Information and Communication Science discipline describes the concepts of cognitive psychology with digital competence in computerization. The overall goal of this work is to provide an HCI component for basic level learning or HCI for the illiterate. It is about transforming a communication tool from a cognitive system to a digital learning tool adapted to the learner's level of digital competence. The author relies on the UML class diagram to identify the affordance and serendipity of HCI property entities. The mathematical study of the similarity between these two properties allows us to update the learner's profile. Stephanie's approach was used when managing the learner's profile and the digital competency taxonomy to classify the learner's level of digital use. The principle of an expert system was taken up in this work to make the decision on the level of digital competence of the learner and to guide the solution so that the learning continues without interruption. This expert system integrates the data science of digital educational materials, defining its specificity. The algorithm of the realization summarizes the implementation of the whole approach. *αβ*Gasy@mobile is an application on Android for Malagasy language literacy. To learn the letter "l" with this application, the initially low-level learner had an intermediate assessment score after 2 hours of continuous learning. Self-constructivism has been developed and strengthened by the HCI illiterate component. We have hundreds of learners for the case study and used ten smartphones to 5 inches. On the selected samples, the results of the experiment are close to our objective. More precisely, the inactive time is almost non-existent, the learning time predefined in the system is close to reality, and the speed of return on the interaction is fluid while the evaluation is notified.

Keywords

Affordance, Component Guide, ETL, Expert System, HCI-Illiterate, Serendipity

1. Introduction

The study on the personalization of Enhanced-Technology Learning Environment (ETL) supposes by definition, the consideration of elements specific to a learning process as it unfolds for a particular learner [1]. The particularity of the learners varies according to their competence those that have an impact on the effectiveness of digital. ETL researchers and designers are increasingly using interaction techniques. The Human-Computer Interface (HCI) is the border between the user and the software. Therefore, different concepts have been conjured up in the evaluation of HCI.

In [2], (Norman, 1968) introduced the affordance concept of HCI to evaluate its usefulness and usability. This approach is a key point in the appearance of the transformed object. However, continuity in the achievement of learning is not reliable. However, serendipity [3] is another cognitive concept that can ensure the continuity of utility in a dynamic way or not. The skill that evolves with time to practice may change the needs. This change will impact the usefulness of the non-customized application. Our goal is to program a new communication feature that will allow low-level learners to be persisted during learning. In particular, the dropout rate in distance formation must be reduced.

In this paper, the authors develop a guiding component for the illiterate during self-learning by exploiting affordance, serendipity, and taxonomy technology in both native language and digital competence. This taxonomy is established through the coupling of (Bunckingham, 2015) [4] and (Plantard, 2016) [5] processes of digital appropriation. Authors use the numerical interaction trace [1], which is an elementary tool for ETL improvement analyses. Our approach is based on the comparative study of an application that integrates an expert system oriented towards education and digital competence with the same application without this expert system.

In the rest of the paper, we state in Section 2 the scientific frameworks for the design of a basic HCI. We elaborate in Section 3 on the methods used to design the guide tool for an illiterate person. The experimentation in Section 4 is discussed in Sections 5 and 6. The conclusion and perspectives on future research work in Section 7 complete our intervention.

2. Related Work

The Human-Computer Interface (HCI) is the border between the user and the machine. It allows the realization of tasks through interactions. A request sent or received according to the context of use corresponds to an interaction. Therefore, the user-centered approach is fundamental for the customization of the HCI tool. The user's needs will be at the heart of the design throughout the software development process [6] [7]. Interactive tasks in a usage domain require the user to have moderate prerequisites for this domain [8]. However, our user is in the naive category. A self-direction is to their necessity to realize the tasks. This self-direction is done through languages whose decoding is easy at their level of competence.

HCI is at the center of the epistemology of natural sciences, art and design [9]. Cognitive psychology creates the models of its environment and behaves according to these models [10]. Thus the affordance of (Norman, 1968) [2], based on the representation of objects developed by (Gibson, 1988) [11], has become a characteristic of HCI evaluation. Serendipity is another cognitive psychological characteristic valued in the ownership of digital content in the era of Web 2.0. (Michels, 2004) [12] defined serendipity is the fact of making an unexpected discovery thanks to chance and intelligence during a search initially directed towards an object different from this discovery. This definition is a technical approach for the design of a user-centered HCI. With web 2.0 and more, it manifests itself via hypertext links and the interconnection of textual, graphic and sound objects. Pre-requisite knowledge of multimodal HCI is necessary when handling or using it [4].

Furthermore, the competence in Web 2.0 usage or digital literacy is the rhetoric of technological moderation. It is also the art of creation and recreation of new to old computer material or digital applications [13]. The authors speak of both digital competence and the ability to decode the language of communication mobilized. Thus, the whole process of digital appropriation [5] and the procedure at the foundation of media literacy in learning [4] contributes to the construction of the elementary components of taxonomy in digital competence at the basic level.

In the ETL, the digital interaction traces approach allows solving the learning reengineering problems. They form a specific element in conducting the study [1]. The Trace-Based System (SBT) is a trace management model (storage, organization, management) most widely used in the current use of traces for ETL [1]. The SBT is structured on the process of collection, transformation and visualization of the trace. It is set up from the principle of a trace object. Semantic processing of traces is sometimes through data mining which requires mathematical and statistical methods for modeling [14].

3. Method

The coupling of serendipity with affordance in HCI is based on the cognitive psychology study of the user. The UML class diagram identifies the objects involved in the operation. The calculation of a similarity indicator between affordance and serendipity balances the weighting of the decision to be taken. The result obtained is carried out in an expert system to produce an HCI adapted to the skill of the user throughout the learning process.

3.1. Affordance and Role in HCI

Affordance is the capacity or potentiality of the HCI to suggest to its user its mode of use or other practice. Since the result of the psychology research (Gibson, 1988) in [11], affordance is one of the key characteristics of the evaluation of the adaptability of HCI. In [15], the studies on the textual exploratory mode of affordance proposed by (Kavanagh *et al.*, 2016) allowed us to establish his model of the UML class diagram is illustrated in **Figure 1**.

An acquired skill corresponds to an adaptation tool or function (**Figure 1**). So, with each acquired skill, the proposed adaptation tool must be modified to transmit another new skill and respect the adaptation characteristic of the interface. And on this aspect the authors integrate the property of the affordance in our design.

3.2. Serendipity and Role in HCI

Serendipity is a meeting place for knowledge, an aspect of chance that leads to intellectual evolution. It is classified among the characteristics of a recommendation system on knowledge transfer [16] [17]. The textual exploratory study of its mode of operation [18] allowed us to establish the UML class diagram model illustrated in **Figure 2**. Other than affordance, serendipity is a core concept/property of an HCI to ensure self-constructivism during computer-assisted learning. In the HCI context, it avoids the temptation to cut or interrupt learning by creating a discovery phase relating to the learning goal.

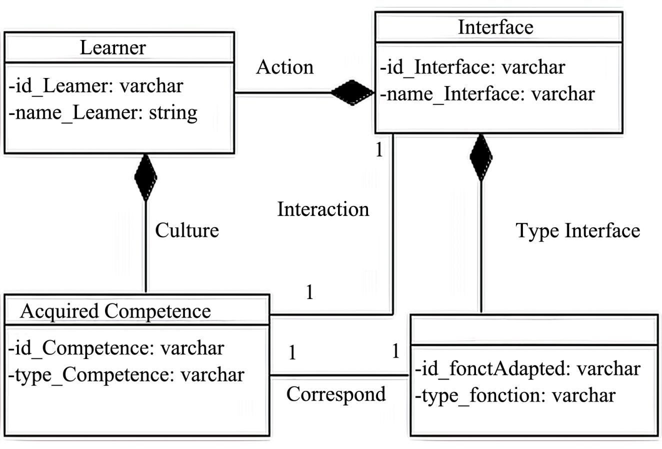


Figure 1. Affordance UML class diagram.

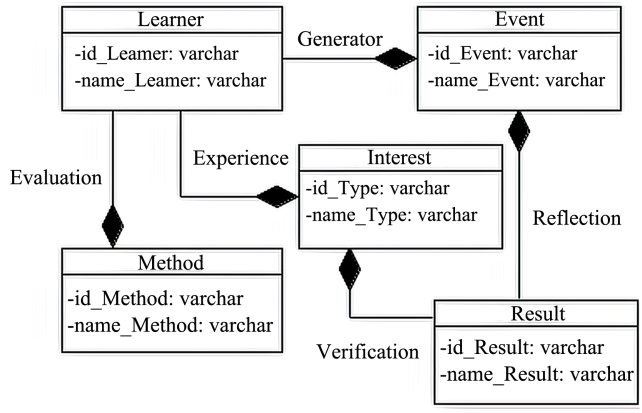


Figure 2. UML class diagram of serendipity.

Entities in the serendipity model are interdependent. The center of interest and the source of the event is the fundamental properties of serendipity. The center of interest has the potential to maintain the learner's motivation, while the event source endorses goal achievement. All of these two properties ensure that the learner's goal is achieved on these properties that serendipity intervenes in our HCI design.

3.3. Indicator of Similarity between Affordance and Serendipity

The study of similarity between affordance and serendipity makes it possible to determine the level of the learner relative to the menu in which the learning takes place. So Salton's cosine similarity indicator [19] is a measure of similarity between two non-zero vectors of an inner product space. In our study, it informs us of the degree of usefulness of the menu to each learner during learning. We have a basis $(\boldsymbol{e}_1, \boldsymbol{e}_2, \cdots, \boldsymbol{e}_n)$ a vector space of property P then, for any vector $\boldsymbol{p}$, there exists a unique $p(x_1, x_2, \cdots, x_n)$ element of P^n such that: $\boldsymbol{p} = x_1\boldsymbol{e}_1 + x_2\boldsymbol{e}_2 + \cdots + x_n\boldsymbol{e}_n$ with $n = 3$ in our case, of which they are defined by the numbers of structured interactions relative to the components of serendipity and affordance.

The formula is given by:

$$\boldsymbol{p}_1 \times \boldsymbol{p}_2 \tag{1}$$

$$\|\boldsymbol{p}_1\| \times \|\boldsymbol{p}_2\| \tag{2}$$

$$sim_{cosinus} = (1)/(2) \tag{3}$$

The value of $sim_{cosinus}(\boldsymbol{p}_1, \boldsymbol{p}_2)$ is in the interval from 0 to 1 or [0, 1], the closer the result is to 1 the more the similarity is close or reliable. As a result, the menu GUI (Graphical User Interface) is more attractive to the learner. It has the potential to keep the learner from achieving his goal without break or inactive time. It has the potential to keep the learner achieving their goal without disruption or downtime. The affordance vector is represented by $\boldsymbol{p}_1$ has as components: the number of interactions on the menu, the interface format mobilized and the degree of satisfaction. The serendipity represented by $\boldsymbol{p}_2$ is composed by the following elements: the number of interactions per event, on the menu, the duration of intervention, and experience. The choice of these vector components was validated after comparing the experimental results obtained with the UML class diagram of each property UTL (Usage Tracking Language) [20] is used to collect interaction data.

3.4. The HCI Guide Component

Given that the profile is a dynamic system, so authors proposed the taxonomy of basic digital competence through the conclusion of the study on digital appropriation and the foundation of digital literacy [4] [5]. Authors rely on the approach of (Duabias *et al.*, 2011) [21] to manage the profile. Otherwise, the guide component in the "*αβ*Gasy@mobile" application supports the completion of the self-study. It is structured by an Expert System (ES) oriented both in education and digital competence. This ES develops a communication tool integrated into the learning platform at the basic level. This communication tool avoids the breakdown of interaction during learning. The knowledge base is based on the language learning model and the taxonomy of digital competence obtained from the research work of (Buckingham, 2015) [4] and (Plantard, 2016) [5]. The language learning model is inspired by pedagogical support at the basic level and is recognized in the field of native language learning [22]. The taxonomy in digital competence shown in **Figure 3** is the characteristics of knowledge on the evaluation of the Human-Computer Interface during learning.

The realization of the ES is based on the development of a self-learning algorithm. Our algorithm integrates an Expert System oriented to both education and digital competence. A heuristic function returns the result of the search in the Knowledge-Based System (KBS) in mother tongue education and in digital competence the competence category of the learner.

- **Step 1: Phase of processing the interactions and updating the profile** [23] **of each learner.** Session management allows keeping track of identification. Then data mining continues the collection of traces. Data mining with the mathematical and statistical method [14] establishes trace semantics. The session and trace semantics are the output variables of this phase.

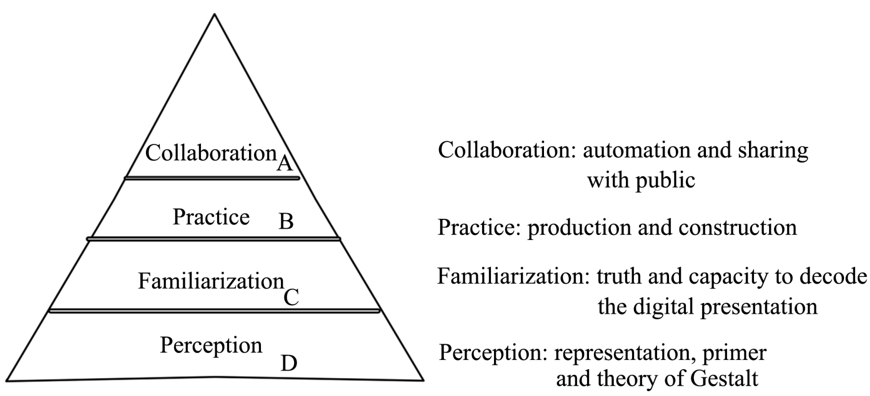


Figure 3. Digital competence taxonomy.

- **Step 2: Position the learner profile in relation to the competency taxonomy.** This position depends on the similarity between the affordance of the HCI and the serendipity. This similarity triggers the skill level of the learner at the instant during learning. The competence taxonomy (Figure 3) defines the level of competence per step on the use of the application. Competence is composed of native language competence and digital competence.
- **Step 3: Establishment of inference rules to make the decision on the choice of the communication tool.** The Knowledge-Based System (KBS) is designed from a pedagogical system of the Malagasy language and the taxonomy of digital competence.

The authors propose an operational algorithm (Figure 4) to execute the programation of the HCI illiterate.

The basic flow chart of the algorithm (Figure 5) to understand the following structure algorithm. It is executed with each layout learning. The choice of the value mediane's data is based on the result of field observation and the study of learner interaction.

```
Input: Interaction's trace, CumulateTimeSys, LevelMenu, CumulateTimeOut,
CumulateEvaluation, VectorP1    /*Affordance component*/, VectorP2
/*Serendipity component*/
Output: Profil, HCI
/*integer i, j, m, n,k
/*Step to put the Expert System*/
FOR i going 1 TO m DO
        Looks up learner skill
        Propose HCI
END FOR
/*Step to extract the value of component affordance and component serendipity,
profil learner*/
FOR i going 1 TO m DO
        FOR j going 1 TO n DO
                processing to affect value profil learner
        END FOR
END FOR
/*Step for value affectation processing of the affordance component and the
serendipity component, and to calculate similarity and classify learner with it's
skill */
IF0 =< (SimCosinus of VectorP1, VectorP2) AND (SimCosinus of
VectorP1, VectorP2) =< 0.4THEN
        verify profil skill learner
ELSE IF CumulateEvaluation =< LevelMenu THEN
        propose HCI
ELSE IF    0.5 =< (SimCosinus of VectorP1, VectorP2) AND (SimCosinus of
VectorP1,
VectorP2) =< 1 THEN
        verify CumulateTimeOut interaction's menu
ELSE    IF (CumulateTimeOut = CumulateTimeSys) THEN
        normal learning continues
ELSE IF (CumulateTimeOut < CumulateTimeSys) THEN
        FOR i going 1 TO k DO
                propose HCI
        END FOR
ELSE
        it is not about learning
END IF
END
```

Figure 4. Algorithm.

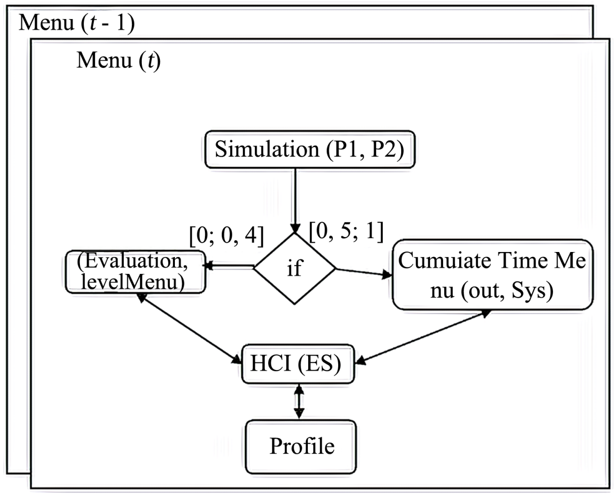


Figure 5. Flowchart of the algorithm.

The custom HCI production mechanism in **Figure 6** generalizes the principle of our programming system. The rules of transformations between HCI models are designed by the Model-Driven Engineering (MDE) approach [24] and deserve an in-depth study in future research works.

ES contains inference rules and learning resources. The profile management system is structured by Personal Information, Preferences, Learning, Characteristic and Learning goal [21]. The latter has access to the original Malagasy image and photo bank. The system is developed with Anaconda to ensure data analysis and management.

4. Case of Study

During experimentation, it had one hundred and ten learners of the same level and aged between 11 and 15 during the 2 hours experiment. Learning takes place at the same time for learners to learn to read and write the letter "l". In the system, the achievement of learning is limited to 79.5 minutes, but the platform is continuously accessible for 2 hours.

Faced with the conditions of self-training, the learner is the master of his organization during the achievement of learning, so we must do the bare minimum over time. The latter is fixed at 2 hours. Each learner has the opportunity to continue learning on another page if he/she finishes the letter "l". During the experimentation, the experimentation has two different groups of learners including the first group learning with the "*αβ*Gasy@mobile" application without the ES and the second group learning with the "*αβ*Gasy@mobile" application incorporating the ES. The comparative study of the data is based on the results obtained. The study of the variance in the execution time to reach the goal verifies the efficiency of our ES.

For the illiterate type user, the authors used the naive type HCI rule. Screen management, content clarity, error management, management of dialogues appropriate to context and comprehensive presentation of the whole in a session

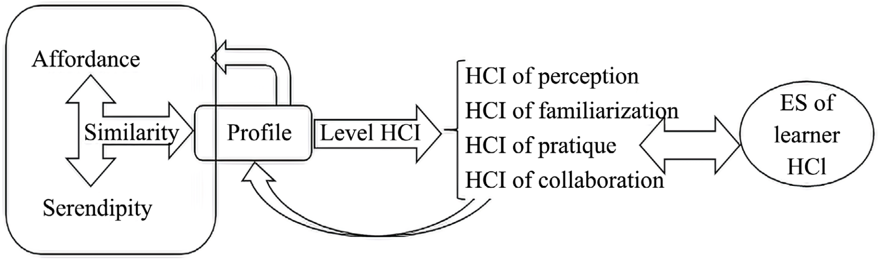


Figure 6. Mecanism of system.

are our concerns during design. We have designed pictograms, pictographs and voice tags so that communication and interaction with the HCI are for the benefit of the learner. The communication with the native language is the strength of the application and also an advantage for learning. At the beginning, the authors adapted the HCI design rules for the naive user type based on the principle of switching from the basic book "Lala by Noro" to a digital application.

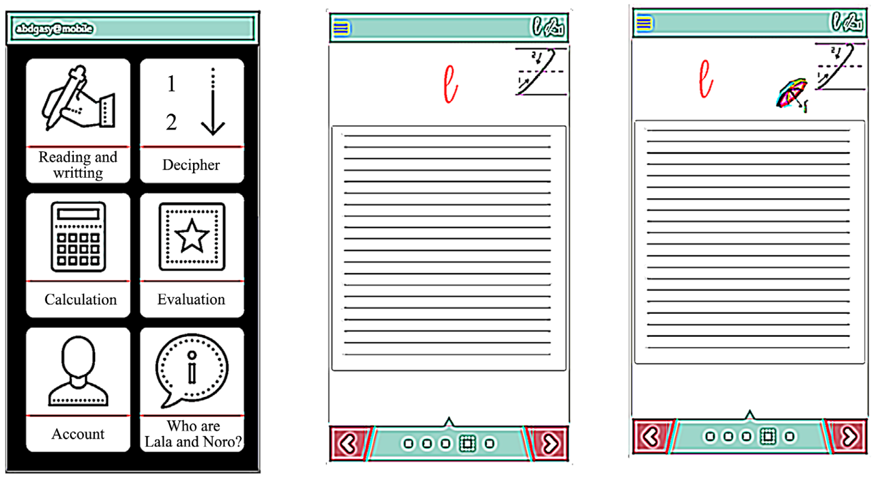
Figure 7(c) is an interface triggered by the ES when the learning time on the menu is exceeded to learn to write the letter "l". The traces made by the learner are processed in the SBT [1]. The transformation module in the SBT sends the trace model browsed, the name of the menu at time *t*, and the time spent from the beginning of the learning and the time on the active menu for an evaluation in terms of duration and attendance. The results of the evaluation are sent to the Knowledge Base (KB) to store the information on the number of times visited, the skills of the menu and the corresponding centers of interest. It is a way to populate the KB.

The KB consists of both knowledges based on the learner's operating modes in the application and the skills acquired in the native language to be learned. The authors are interested in the operating modes of the application in this article. To determine the status of the learner at the moment, the heuristic function deploys the KB to search for the solution. The return of allows the application to choose the HCI to display at the moment in the active menu.

The A2 learner group used this option during our experience. To learn the letter "l", the system recommends displaying an umbrella that reads in Malagasy "elo" or [elou] in multicolor on the right side at the top of Figure 7(c) in case the learner is on the difficult status. This icon moves to the middle of the learning space and grows as soon as the learner's finger touches it, scrolls when flicked to the right and deletes when flicked down. This is the guide component of learning. The child knew this but had not yet seen an umbrella of multiple colors at once.

The indicator of similarity between affordance and serendipity reinforced by the learner's ability to describe a new object appears on the screen as soon as a value is returned. The HCI in Figure 7(c) is one of the possible types on display provided by the ES.

Table 1 summarizes the results of the experiment. The total duration to learn the letter "l" is 79 minutes and 5 seconds and the platform remains accessible



(a) (b) (c)

Figure 7. Home menu application screenshot (a) with affordance (b) with ES (c).

Table 1. Results obtained at each duration of passage in a menu.

Menu	Characteristic HMI with and without serendipity		
	Preset duration in minutes	HCI with affordance A1 in minute	HCI with SE A2 in minutes
Guide L	7	14	10
Illust L	8	8.5	8
Lec "l"	7	20	11.8
Eco "l"	8	16	9.4
Rep "l"	9	10	6.3
EvaL "l"	12	10.9	12
GuideE	7	-	10.1
Mod "l"	8	-	6.9
Ecri "l"	8.5	-	8.7
EvaE "l"	12	-	11.2

for 2 hours continuously. Learners do not necessarily have to respect this duration. The observation of the experimental data obtained lasted two hours during the day. The average of the scores obtained for the two groups shows that they are at the same level in the mastery of handling a smartphone. The authors chose the performance configuration (ITEL A16+, 1G of RAM) of the smartphone to avoid all connection problems and slowness. SBT retrieves the learning traces and processes them according to the sent request. For the 10 menus to browse in the application, the output of the transformed trace gives us the information in **Table 1**.

We have ten main menus to learn a letter in the application. A home page presents these menus and proposes a navigation guide in the Malagasy language in video format. And we have the menu layout, the colors used, static illustration, animated illustration, dialog window, free space to practice, the possibility to move on a screen page, the number of pictograms per screen page, the audio-visual, the guide and the new HCI component for a self-learning guide. This last component is the integration of the cognitive psychology serendipity and affordance fortified by the level of competence. The function ensures the type of HCI to be launched.

5. Performance Evaluation

The analysis of variance on the continuity of the A1 learner group and its realization in the function of the simple affordance is summarized in **Table 2**.

The analysis of variance on the continuity of the A2 learner group and its realization as a function of the ES is summarized in **Table 3**.

The comparison in the study of the variance of these two tables confirms that the use of the expert system is more efficient than that of the HCI with a simple affordance.

6. Discussion

The variation study in **Table 2** and **Table 3** confirms the effectiveness of the existence of a self-learning guide component. It is classified among the decision tool on the orientation of the learner during the learning. The variance in the duration of manipulation of the group of learner A1 amounts to 56.958 which is larger compared to that of the variance of the group of learner A2 which has the value 5.52. The ES, the learner's guide, supports the learner's attention to reach the pedagogical scenario. From the third menu, the ES provides the self-learning guide component so that the learner can continue learning from another angle without interruption. To learn the reading of the letter "l", the application displayed a new audio-visio of type new knowledge (**Figure 7(c)**. In this situation, learner A_{26} (learner belonging to group 2 and number 6) has exceeded the duration

Table 2. Analysis of variance on learner presence as a function of affordance.

Source of variation	Analysis of variance A1		
	Degree of liberty	Sums of squares	Variance
Between learners	1	1.100	56.958

Table 3. Analysis of variance on learner presence as a function of ES.

Source of variation	Analysis of variance A2		
	Degree of liberty	Sums of squares	Variance
Between learners	1	925.5	5.52

Table 4. Example rule base at the perception level.

Fact base	The rule base
1) Event (interaction) 2) Symbol (color) 3) Gesture (repetitive, i) 4) Message (error, 0) 5) Form () 6) Menu (object, x) 7) Fund (x)	R1: (Symbol (color), Event (interaction), Message (Error, 0)) → Form (1); R2: (Menu (object, 1), Gesture (repetitive, 0)) → Fund (object)

predefined in the system. The value of the similarity has $Sim_{cosinus}(\boldsymbol{p}_1, \boldsymbol{p}_2) = 0.35$ and $CumulateEvaluation = D^-$ which is less than $level(menu) = D$. This means that the learner encounters difficulty.

The affordance property is dominant at the beginning of learning. They manage to respect the duration for the first two menus (**Table 4**). On average, the two groups of learners achieve their goals in different ways. Group A2 continuously browsed through the menus they were to visit for a duration of 94 minutes and 4 seconds. While the A1 group needed more time to reach their goal. In terms of functionality and user guide, the application represents an ability to adapt to the needs of the illiterate learner. The "utility" property [13] [25] [26] is acquired for the proposed HCI at these moments.

In terms of the quality of the HCI that facilitates learning and use, other than the acquired knowledge of the domain, serendipity with competence has held a part in this success. The learner interacted with the cognitive concept at each presentation of a hazardous element. This last element plays an important role in the continuity of the interaction and also generates a new discovery always in the field of learning corresponding to the functionality of the menu at the moment *t*. The cognitive guide component reinforced the "usability" [13] [25] [26] property of the application even though it appears when the ES notices a slow learner.

Another feature found in the result shown in **Table 4** is the speed of realization of group A2. The speed of interaction at each menu is varied but the time to go through the paths to the last menu is acceptable compared to the time set in the system. The speed is calculated in relation to the duration and the number of interactions carried out. After an exchange with a pedagogue, learning without interruption is experienced from the existence of the motivation that generates the endurance of the individual. This individual performance is acquired if he receives help or guidance as soon as he feels blocked during the realization. The type of our cognitive guide component provides this functionality.

7. Conclusion and Perspectives

The authors have developed an HCI component for learning at the basic level. He emphasized the concepts of cognitive psychology with digital competence during computerization. Authors worked on the ergonomics, Artificial Intelligence (AI) and mathematical method branches to have a digital design of a learning HCI for illiterates.

On the samples chosen, the results of the experiment are close to our objective. More precisely, the inactive time is almost inexistent, the learning time predefined in the system is close to reality, and the speed of feedback on the interaction is fluid while the evaluation is notified. The learners in group A1 resumed their learning the next day by spending more time with the cognitive guide component.

This is a multidisciplinary study (Human Sciences, Cognitive Sciences, Ergonomics, Artificial Intelligence) that deserves in-depth study in user-centered HCI development. The variety of serendipity and affordance does not facilitate the study of this type of development. It is necessary to have an expert Knowledge-Based System (KBS) at each level of digital competence. This work consists of a first model of an HCI for illiterates in the tropical zone.

Our future work is based on the modeling study of these different levels of competence in digital **Figure 3** to be able to integrate them into the recommendation system of the application. We could use Model-Driven Engineering (MDE) for design and realization.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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