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Ningxi Chen[1], Adrian Roussel-Fayard[1], Nadine Vigouroux[1], Jean-François Camps[2], Charlotte Tabarant[3], Frédéric Vella[1]

[1] IRIT,CNRS, UPS, 118 Route de Narbonne,
F-31062 Toulouse CEDEX 9, France
{Nadine.Vigouroux, Frederic.Vella}@irit.fr
[2] URI Octogone-Lordat, UT2J, 5, allée Antonio Machado,
31058 Toulouse CEDEX 9, France
jcamps@univ-tlse2.fr
[3] academic's direction, french national's education
charlotte.artus@ac-toulouse.fr

Abstract. This article report the principles and the design of usability method used on HMK-Learning application. It is a digital tool for students at primary schools in France based on Mounier's numeracy work in didactics. Firstly, the design method of HMK-Learning is described. Then, we describe the survey design method to study the usability of HMK-Learning. This questionnaire is based on Nielsen's and Alsumait's heuristics. Next, we present the survey results answered by four teachers of primary schools. We mainly report them from the point of view of the design interface elements. The study underlines the importance of offering interaction and feedback techniques adapted to the motor and cognitive abilities of elementary school students.

Keywords: usability, primary school, mathematics digital numeration

1 Context

Trends in International Mathematics and Science Study survey (2019) ranks France last in the European Union countries for the level of knowledge in arithmetics compared to statistics, probability and geometry. In France, the mathematics Villani-Torossian report notes learning difficulties (sense of numbers, counting, transcoding between oral and written numeration, etc.) in mathematics from primary school. A recommendation of the report concerns the meaning of the four operations (addition, subtraction, multiplication and division) and the teaching of the quantities and measures in primary school that should support number and operation sense. Moreover, [1] and [2] demonstrated the good influence of digital tools on student's development of skills and mathematical knowledge. [2] highlighted the fact that "the success of digital technology in mathematics education include the design of the digital tool and corresponding tasks exploiting the tool's pedagogical potential, the role of the teacher and the educational context”. Based on these findings, our hypothesis is that the design of HMK-L application integrating Mounier's [3] numeracy work could be more efficient for students at primary schools in France. More precisely, Mounier worked on acquisition of the “sense of numbers”, the organization of collections, oral-written transcoding of numeration information, the concept of numeration of position. In HMK-L, we will experiment the comparison of collections with an analysis of the numerical manipulation of tokens. The observation is focused on strategies of moving tokens, to group tokens or not in order to study the efficiency of installing the need to group by 10.

The aim of this paper is to describe the design method of the application HMK-Learning for pupils at primary school. Then, we will focus on the survey design method to study the usability of HMK-Learning. Finally, we will present mainly the results of the usability study on the interface elements and they will be used in the design method of HMK-L.

2 Design methodology of HMK-L

Together with a mathematics Villani-Torossian-65 (France) group, we designed the HandiMathKey Learning (HMK-L) through a participatory design approach. The particularity of our approach concerns the involvement of the ecosystem in the sense of Guffroy et al. [4]. This ecosystem is composed of 5 primary school teachers, an Expert in Mathematical Didactic and pedagogy, 3 researchers in Human Computer Interaction (HCI) and 1 cognitive psychology researcher. A first activity developed was the comparison of numbers. The constraints of use were that primary school children did not have a sufficient reading level for instructions, and that the interface should be simple to use and fun. The other constraint concerns the running of the application on any operating system. We chose the choice of a web application (https://www.irit.fr/HandiMathKey-Learning/). We describe below the design method of the student interface of HMK_L.

Firstly, the mathematics Villani-Torossian-65 (France) group has written the specifications of the comparison of numbers application (case study scenario, interface for configuring interaction techniques and token colors). Then, the HCI researchers has designed a first low fidelity prototype with the following interactive components (see Fig. 1): 1) the button to return to the home page; 2) the help button for handling the tokens; 3) the textual instructions 6) the 2 classes of tokens to be compared; 7) the button to be selected for the choice of the correct answer; an animation and audio feedback are given according the answer 8) the digital tape to help the pupils visualize the quantity of tokens. Representation of the tokens, modality of the instructions, animated help; feedback on evaluation of the student's response; interface design (simple, aesthetic and fun aspects) have been discussed with the mathematics referent regarding their design for children. The teachers’ group has then expressed two new needs (see Fig. 1): 4) the level of the exercise; 5) the pictogram representing the child's progress in the exercise. This representation has allowed the pupil to monitor his/her advances. The second high-fidelity prototype takes into account the decisions of the focus group (see Fig. 1)/

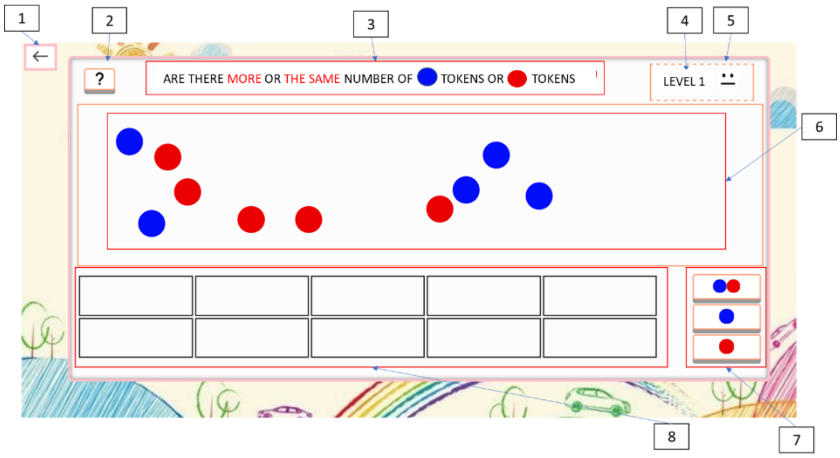

Fig. 1. The interface of the number comparison exercise

Another strong demand is the ease of interaction in manipulating collection tokens for students with motor disabilities so that cognitive processes are primarily dedicated to the task of learning and reasoning and not to solving token manipulation problems.

The HCI team has designed three interaction techniques: (Drag and Drop (DD), Click to Click (CC) and Magnetization by Click (MC)). The pupil with or without motor disabilities has thus the option to select the one that is most appropriate for him after manipulation trials.. [5] have studied these techniques for object manipulation for patients with cognitive disorders. The interaction device has been evaluated as a usability indicator and will be evaluated in the future with users directly.

3 Usability Questionnaire

3.1 Several approaches

Two main types of methods can be used to evaluate usability of interactive system: heuristic and standardized survey. Heuristic evaluations are mainly done by human computer experts during the different phases of the design. User experience, on the other hand, involve users (final or secondary) who are not experts in human computer interaction but who can identify concrete problems when using the application to be evaluated. The most well-known questionnaires are: SUS (System Usability System) [6] and USE (Usefulness, Satisfaction and Ease of Use) [7].

Nielsen [9] is the reference for usability heuristics. [8] have proposed 21 Heuristic Evaluation for Child E-learning based on Nielsen's heuristics and adapted to children and e-learning applications. Ssemugabi and De Villiers [10] proposed in 2007 a comparative study between a set of 20 heuristic evaluation and a user survey. They concluded that heuristic evaluation is cheaper, more efficient and easier to implement than user survey. On the other hand, the problems found using heuristics, although more numerous, are less important and less related to the context of use of the evaluated application.

The output from using the heuristic evaluation method is a list of usability problems in the interface with references to those usability principles that were violated by the design in each case in the opinion of the evaluator. We have chosen the heuristic evaluation because firstly, we want to identify the problems during the design phase and secondly, 75 % usability problems in an interface are found by heuristic evaluation using five of evaluators.

3.2 The Design of the Usability Method

In the health context of COVID in March 2020, our approach was to design a remote evaluation. This makes it possible to overcome the heavy constraints associated with face-to-face work (social distancing, cleaning of experimental equipment, etc.).

A multidisciplinary team (1 cognitive psychology researcher, 2 researchers, a student in human-computer interaction and an expert in mathematical didactic and pedagogy) has designed the questionnaire. We used the set of 21 heuristics proposed by Alsumait and Al-Osaimi [8]. These heuristics are highly relevant for the usability study of HMK-L because they are based on Nielsen's heuristics (see Fig. 1), adapted to children and e-learning applications. The Table 1 gives the distribution of the 47 criteria to the ten Nielsen’s Heuristics as illustrated below.

While this approach allows for the respect of health conditions, it does raise some adaptations in its implementation. Indeed, it is necessary to ensure: 1) that the questions are understandable by the evaluators since the experimenter is not present and 2) that the evaluator has discovered all the functionalities of the interactive system. To meet objective 1, the comprehension of the questionnaire was presented to two teachers of primary school and a representative member of the mathematics Villani group who checked the comprehension (objective of the question, meaning of words) of version 1 of the questionnaire. After this focus group, we corrected ambiguous questions. The questionnaire contains 65 questions using 76.6% of the criteria of Alsumait and Al-Osaimi. The Table 1 gives the distribution of criteria according the Nielsen’s Heuristics as Table 2 gives the links between of the question, the Nielsen’s Heuristic and Alsumait’s criteria.

Table 1. Distribution of criteria used according the Nielsen’s Heuristics used (extracted from [11]).

Nielsen’s Heuristics	Number of criteria used	Number of criteria by category	Percentage use of criteria
Visibility of System Status	6	8	75%
Match between system and the real world	4	5	80%
User Control freedom	3	4	75%
Consistency and standards	4	6	66,67%
Error prevention	3	4	75%
Recognition rather than recall	3	4	75%

Table 2. Links between the questions, the Nielsen's Heuristic and Alsumait's criteria.

Tasks	Nielsen's Heuristics	Alsumait's criteria	Question
	Consistency and standards	Control keys are intuitive, convenient, consistent, and follow standard conventions	Is the interaction technique useful for picking and moving the ball?
Choice of the interaction technique	Flexibility and efficiency of use	Input/output devices are used for their own purposes and are suitable for the specific age group of the child	Do you feel these interaction techniques are appropriate for use with students?
	Help and documentation	The child does not need to use a manual to use the application.	Is the interaction technique easy to understand? There is no need to explain how to use it.

Table 3. Examples of question for the task "Choice of the interaction technique".

Questions	**Answers**
Is the interaction technique useful for picking and moving the ball?	Likert scale : Absolutely not convenient (0), Not convenient(1), Somewhat not convenient (2), Somewhat convenient (3), Convenient (4), Perfectly convenient (5)
Is the interaction technique user-friendly? There is no need to explain how to use it	Likert scale :Very difficult (0), Difficult (1), Rather not difficult (2), Rather not easy (3), Easy(4), Very easy(5)
Is the interaction technique easy to understand? There is no need to explain how to use it.	Verbatims

A scenario of tasks and subtasks is associated with the questionnaire. The evaluator must perform a sequence of actions with the HMK-L application and then answer questions about these actions. We will illustrate the principle on manipulation tests with the two interaction techniques (DD and CC) described in section 2.

Task: Choice of the interaction technique

Action : Click on "interaction technique" to open the menu for the selection of an interaction technique

Sub task 1.1 : Drag and Drop

Action : Select the "drag and drop" interaction technique.

Action : Put the football ball at various locations in the test area to test the interaction technique.

Subtask 1 will be duplicated for the CC interactions.

Table 3 shows three questions and the type of response expected for each of them.

The questionnaire consists of 65 questions (37 closed questions, 11 questions with a Likert scale and 17 open questions).

4 Results of the usability questionnaire

An expert in mathematical didactic and pedagogy presented the objectives and principles of the HMK_L application to 5 teachers of primary school. During health confinement in November 2020 in France, the document containing task scenarios and questions was sent to them. 4 of them responded. On the overall, according to users' feedback, the HMK-L digital application is identified as an interactive, useful and practical tool to develop skills in numbers' comparison and overall in numeration. Table 4 summarizes the evaluation on interface elements.

Table 4. Evaluation on interface elements

Interface elements	Evaluation report
Visual aspect of the interface	Pleasant, airy, understandable, playful and well-structured;
Textual instructions	Understandable, presentation in sound modality required
Spatial layout of tokens	Good distribution, token overlapping to be avoided, no need of audio feedback
Feedback	Progress scale for exercises is suitable, feedback of success or failure is also appropriate
Interaction techniques (DD and CC)	Ease to use, Ease to understanding

The textual instructions (button 3 in Fig. 1) is considered readable (4.75 on a 5-point Likert scale) and the application combine aesthetics and ergonomics design (4.25 out of 5). The scale of progression in the exercises (change of color of the smiley and the level label: button 4 and 5 in Fig. 1) is concerned as encouraging and understandable for 3 primary school teachers. The two verbatims confirm this point of view: "Related to what is used in class". "It is motivating". The last suggests improving the smiley representation to distinguish better the levels of exercise: To questions, --"Why not keep the same smiley face with a progression of colors? " What do you think of the animations (image, sound and animation of the tokens) linked to the expected correct answer or the erroneous answer? Do you think they are suitable for students? Do they encourage further use of the application?--. The animations broadcast according to the student's results are very playful and fun for 4 of the teachers for a correct answer and only 3 for an incorrect answer (verbatim : "Very good, these animations are very playful and visual: the children will perfectly associate each pictogram and the sound, either to a success or error; they are very motivating. Be careful with the animation of the tokens a little too fast according to the level and a little clutter (several tokens are arranged at the same time)". However, the teachers also suggested that in the case of an incorrect answer, it would be preferable to put a picture a little more encouraging for the child. The role of the digital tape is also understandable for the students according to the 4 teachers. The arrows for navigation through the exercise (go to the next exercise, repeat the exercise, go to the next level of difficulty) are affordable.

We compare the ease of understanding and use of the two interaction techniques (DD and CC). For these variables, we used a 0-5 point Likert scale. The DD technique is considered slightly easier (5 vs. 3.66) and (4.66 vs. 4.33) by the teachers (see Table 3 for scale values). Feedback from selecting (4.66 out of 5), moving (4.33) and releasing (4.66) a token was perceived as visible. The teachers validated these two dimensions of the interaction (modes of control of token movement and feedback of the student's action in the interface). However, studies of use by students with motor and/or attentional disorders should confirm these results. At this stage of the design of HMK_L, this postulates to allow the choice of the interaction technique as a parameter of the HMK-L application.

The implementation of the usability method linking controlled scenario and questionnaire provided relevant input for the redesign of HMK-L. Indeed, the results of this usability study are currently being taken into account for the development of the 2nd iteration of the HMK-L application before usage studies are performed by children.

5 Conclusion & perspective

A multidisciplinary team has designed a questionnaire based on Alsumait's criteria and Nielsen's heuristics to evaluate the HMK-L design. However, the health constraints due to the COVID 19 pandemic have affected the usability method implemented. We initially measured the understanding of the questionnaire with 4 teachers. On the overall, according to primary teacher's usability test, the HMK-L is identified as an interactive, useful and practical tool to learn and to develop skills in numbers' comparison and overall in numeration. The questionnaire analysis is very rich and usable to redesign interaction components (instruction, progress feedback, etc.) to improve ergonomics and accessibility of HMK-Learning by students. It also demonstrated the relevance of the application's feedback and the interaction techniques implemented.

The main limitation of our study is the insufficient number of evaluators. The next steps are : 1) usability and utility test for primary school students with the release of HMK- following the consideration of the usability study by the teachers; 2) the analysis of the movement of the tokens with or without a specific method, the modalities of grouping will allow us to deepen our knowledge in particular of the relations between space and number and of the numeration of position.

Acknowledgment

This project was partly funded by the MSHS-T in Toulouse (France). The authors would like to thank the teachers from the primary schools who participated in the HMK-Learning specifications and who answered the questionnaires.

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