A USER-INTERFACE ENVIRONMENT AS A SUPPORT IN MATHS TEACHING FOR DEAF CHILDREN

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Abstract: The use of theories stemming from different areas of knowledge has contributed both to knowledge acquisition – since these theories help perceive individuals more effectively – and to the development of educational software. This is the case, for instance, of cognitive theories, which in turn assist in terms of both learning support and the clarification of possible needs in the acquisition of a given concept. In the present paper, we propose a discussion about the help function (Leite, Borba and Gomes, 2008) provided by educational software, focusing deaf students. This paper also presents an enhancement for the interface design of the help function, based on the Conceptual Fields Theory and the Theory of Multiple External Representations. This interface design enhancement is created by carrying out a new analysis regarding the display of a help function through diagrams. In short, in the present paper we derive important contributions from these two theoretical frameworks so as to provide deaf students with support in the acquisition of mathematical concepts, considering that these deaf students are put in an inclusive context.

1 INTRODUCTION

In recent years, the use of technology as a supporting resource to cognitive development has become increasingly sophisticated, leading to a number of interdisciplinary efforts involving areas such as Psychology, Pedagogy and Design, amongst others. Furthermore, these technological tools have been taking increasingly more notice of the users' specificities.

Psychology has been paramount to understanding both user-interaction and knowledge acquisition, particularly when it comes to designing educational software.

A number of new educational projects point towards the need to develop interfaces that fulfil the demands of users with countless communication needs. Indeed, deaf users are a good example of these users.

Different studies have revealed that deaf students tend to have even more difficulty with Mathematics than hearing students. In fact, research (such as Austin, 1975; Kelly, Lang, Pagliaro, 2003; Kelly, Lang, Mousley, Davis, 2003; Nunes, Moreno, 2002; Traxler, 2002) has shown that deaf students today have great cognitive gaps when compared to hearing students. The reasons for such gaps are of linguistic and experiential nature, since hearing students and deaf students acquire and develop language differently (Bull, Marschark, Blatto-Vallee, 2005 ; Zarfaty, Nunes, Bryant, 2004). This way, deaf students have different social experiences, and this fact moves the two groups, i.e. deaf students and hearing students, further apart.

The different perspectives underlying the education of deaf students, particularly in terms of the way language is handled, have led to the development of specific educational philosophies, which in turn resulted in a significant educational lag (Kelly, Lang, Pagliaro, 2003). Indeed, oralism – the practice of teaching hearing-impaired and deaf students to communicate through spoken language – and bilingualism – the practice of teaching hearing-impaired and deaf students to communicate by respecting their natural language and associating it to the native language of the country in question – make up completely different philosophies. This means that a change in paradigm would entail drastic changes in the actual teaching process.

The range of products developed specially for the deaf remains rather limited, though in certain

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areas of knowledge one can find a large number of translators or translation-related products for Portuguese and Brazilian Sign Language. Products such as these may even fulfil the needs of the deaf as far as communication is concerned, but they certainly do not make the inclusion of deaf children into regular or mixed classrooms any easier, nor do they fulfil the demands posed by specific areas of knowledge, such as Mathematics, for instance.

The study of Leite, Borba and Gomes (2008) proposed the design of an human-computer interface for an educational software wich presented the help function interaction based on the Conceptual Field Theory (Vergnaud, 1986). The present work enhances the first proposing contributions by the application of the Multiple External Representation Theory (MRE) (Ainsworth, 2006).

The present article is organised in the following way: initially we carry out a brief discussion of the difficulties faced by deaf children learning Mathematics. After that, we present both the main presuppositions of the Conceptual Fields Theory and the contributions of the Theory of Multiple External Representations. Next, we describe the contributions for the interface design using Multiple External Representations. Finally, in the last two sections we carry out a discussion of the results obtained and present our conclusions.

2 DEAF CHILDREN AND THEIR LEARNING DIFFICULTIES IN MATHEMATICS

The need to coordinate knowledge acquired inside and outside school with teaching-learning activities has been emphasised in the case of hearing children (Carraher, Carraher, Schliemann, 1988), but it is also valid for deaf children, particularly when one bears in mind that these children tend to lag behind in terms of age group/level of education (Traxler, 2000). If the previous knowledge acquired by deaf children is not taken into account, their cognitive development may be compromised.

Informal learning also has some impact on the acquisition of mathematical knowledge. Therefore, knowledge stored implicitly prior to school age might need to be reviewed. One example of that is additive composition, whereby any given number may be perceived as the sum of other numbers, which in turn is a concept that can be learned before school age with money or other items. Another element that may lead to difficulty is inferences about time. Deaf children have far more difficulty than hearing children with activities involving time in a succession of events, and this is a key ability in the learning of the inverse relation between addition and subtraction (Nunes e Moreno, 2002).

Different authors (Bull, Marschark, Blatto-Vallee, 2005) assert that the fact that deaf students tend to lag behind in terms of mathematical abilities is intimately related to cultural factors of language acquisition. Indeed, the lack of coordination between linguistic, symbolic and analogical means of representation of numbers may lead to difficulty in the acquisition of arithmetical concepts. On the one hand, hearing children learn certain correlations by using visual and auditory information – e.g. when they correlate objects to the oral expressions that represent them. On the other hand, deaf children need to watch and correlate two kinds of visual information in order to carry out the same activity. Therefore, even though both hearing and deaf students have difficulties in learning Mathematics, there certainly are peculiarities in the way deaf students learn it.

Poor overall linguistic knowledge and competence may be the main hindrances for deaf students to learn Mathematics. Both cognitive development and experiences lived through inside and outside the classroom are directly related to linguistic issues. Low linguistic development affects the relationships and experiences of deaf children, potentially harming their cognitive development (Zarfaty, Nunes, Bryant, 2004).

Many of the inherent learning difficulties – Mathematics being an example of it – faced by the deaf have a lot to do with late language acquisition. This calls for the adoption of special teaching practices rather than traditional ones.

3 THE THEORY OF CONCEPTUAL FIELDS

The main theoretical framework of Conceptual Fields Theory (CFT), in which Leite, Borba and Gomes (2008) based their study, was created by Gérard Vergnaud's (1986). According to it, a conceptual field consist of a set of situations whose domain requires the knowledge of numerous other concepts of different natures. As Vergnaud (1986) explains, a concept is like the base of a tripod, as follows: Situations that provide concepts with meaning (S), Invariable Relations and Properties of the concept (I), and Symbolic Representations used in the presentation, description and operationalisation of the concept (R). The analysis of word problem, together with the study of the processes and symbolic representations used by students when discussing and solving word problems, is the key element of the above-mentioned theory (Vergnaud, 1991).

Vergnaud (1986, 1991) asserts that, in order to solve a word problem, one must employ a great number of theorems, i.e. knowledge equivalent to the properties of a concept. When doing so, one resorts to abilities and knowledge that Vergnaud (1986, 1991) names theorems-in-action. In short, theorems-in-action refer to representations of the relevant aspects of the action in question. Indeed, these representations reveal only the essential aspects of the action.

In more practical terms, one could speak of concrete elements (such as sticks, marks on paper, fingers) as the invariables employed. Since the response offered would certainly not be the quantity of material used, but rather the quantity about which the question asks through the representation, the objects used are not relevant; instead, what matters is the result.

Although word problems are worked on all through elementary and secondary school, their diversity is not fully explored as that would require the use of numerous situations involving countless invariables. What one normally does use is a limited range of additions, subtractions and properties of these operations. Similarly, the number of forms of symbolic representations of these operations is also limited (e.g. Charlie has 6 cars and Paul has 8. How many cars do they have altogether?). This kind of limited work makes students employ a reduced amount of specific knowledge and present difficulties when solving other problems which, in turn, require the use of different meanings, properties and representation forms.

An instance of word problem characterised by *change* would be the following: “Mary used to have 14 letter papers. Her mother gave her 8 more. How many letter papers does she have now?”, whereby a change happens to an initial number, resulting in a new number. In other words, an initial number goes through a direct or indirect transformation, causing this initial number to grow either bigger or smaller. As we can see, the idea of time is implicit in a word problem like this one, making it an invariable that needs to be taken into account in order for one to find the solution.

Vergnaud (1986) divided addition and subtraction problems – isolated or combined over natural, integer or real numbers sets – into six categories. Carpenter and Moser (1982), as they explore natural numbers only, divided the problems on four categories: combination, comparison, change and equalisation. These 4 categories give rise to 16 different situations, depending on where the unknown number is located.

The Carpenter and Moser (1982) classification was adopted by Leite, Borba and Gomes (2008), which proposed a help-function using a different diagram form for each one of the four problem categories.

4 VIRTUAL ENVIRONMENTS AND THEIR MULTIPLE REPRESENTATIONS: SUPPORT TO TEACHING AND LEARNING ONCLUSIONS

The Theory of Multiple External Representations (Ainsworth, 2006) is a cognitive theory that advocates the use of specific techniques to represent, organise and present knowledge. MERs have the following three key functions: complementary roles, constrain interpretation and construct deeper understanding.

The first function, “complementary roles”, explores representations that, for being of different types, complement each other and offer support to the cognitive process. The main objective of the “constrain interpretation” function, on the other hand, is to use representations that helps the learner to avoid misintrepretations about the concepts in question. Finally, the “construct deeper understanding” function uses MERs as a tool for helping the learner to buid abstractions about the concept and organize it in a higher level.

According to Ainsworth (2006, 2008), representations may appear simultaneously or alternately. Either way, learners must be able to understand the form of representation, its relation to domain, how to select an apropriate form of representation and how to create an appropriate one (Ainsworth, Wood, Bibby, 1996). This way, one can construct new representations and access other representation options which, in turn, help expand the conceptual field in question.

Having a wide range of representations may result in more effective learning conditions, particularly when these representations provide learners with a more in-depth view of the concept in question, or when they suit the user’s cognitive model. Furthermore, making use of more than one representation type may help grab the students’ attention for longer (Ainsworth, 1999).

Nevertheless, in order for the system to be truly advantageous, i.e. in order for these functions to actually be fulfilled, the design of a Multiple External Representations environment must follow certain rules, presented at the framework Detf (Ainsworth, 2006).

As Ainsworth (1999) explains, MERs may be used in numerous computer contexts and in combination with users' profiles and their own representation preferences. In this case, we would have both the communication specificities and the mathematical invariables needed to employ a concept described within CFT.

The main contribution made by the MERs to the present study lies in the "complementary roles" function. Indeed, as already pointed out above, this function sugests that the use of different representations stimulate learning further when compared to single representations (Ainsworth, 2006) – which, by the way, is what CFT advocates as well (Leite, Borba, Gomes, 2008). Another great advantage of MERs is that fact that they are research objects in learning, cognitive sciences and constructivist theories.

5 COGNITIVE THEORIES: CONTRIBUTIONS

Educational software does not always take into account how able users may or may be not to understand a concept, or the use of trial and error.

The interface design proposed by Leite, Borba, Gomes (2008), for example, uses CFT because it offered the necessary framework to solve problems across different categories (combination, comparison, change and equalisation).

At Leite, Borba, Gomes (2008), the use of help through diagrams consists of presenting an image that helps users to start building the concept in question. To develop it, they used Vergnaud's invariables for each kind of problem. The authors intention was to help learners to employ the correct invariable, as well as to enable them to complement the knowledge that may be lacking or incomplete.

Indeed, the use of diagrams to assist in the resolution of problems is largely explored in the first school years, when certain concepts are gradually being formalised. Even though images may be revealing and clarifying, formalising concepts is necessary for further generalisations. In any case, learners, which have difficulties, should choose the option that suits them better. The study of Leite, Borba, Gomes (2008) showed that the more choosed option was the diagram form.

Let us take a problem, presented in Leite, Borba, Gomes (2008), in which combination is involved: "Peter has bought 15 oranges, and Helen has bought 6 oranges. How many oranges have they bought in total?". In this problem, one must employ the invariables of a static relationship between two quantities and their parts. In this light, we have come up with a diagram (Figure 1) exploring two separate sets of objects (parts) and then the whole set formed by their addition. In this specific case, we had a character and a certain number and another character with another number, with a thin line separating them. By using a circle surrounding both characters, we expressed the addition of the elements. Therefore, our intention was to show how a certain whole is made up of parts, and one can determine the whole by knowing the parts – or determine a part by knowing the whole and one of the parts.

At the referred study, the use of diagrams was its major contribution. The use of a diagram allow to more easily explore the perceptual process, once it groups the informatiom in a more cohesive form (Ainsworth, 2008).

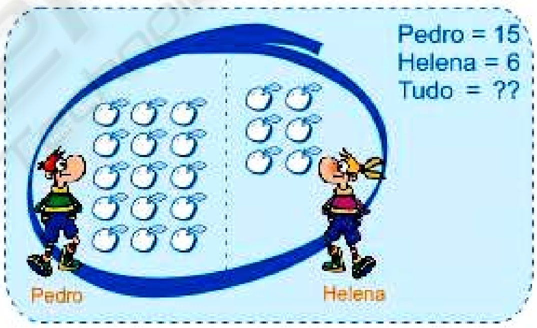

Figure 1: Combination Diagram (Leite, Borba, Gomes, 2008).

As Ainsworth (2008) asserts, sets of information that are typically bound to different dimensions will dificult its comprehension if they are put all together in one representation. The use of different representations, one for each set will make the comprehension more confortable to the learner

Let us now turn to a problem of comparison, presented in Leite, Borba, Gomes (2008), namely "Peter has bought 10 oranges, and Helen has bought 6 oranges more than Peter. How many oranges has Helen bought?". When it comes to static numbers, diagrams (Figure 2) allow one to identify one number by adding another number to a pre-existing static relation. In this specific case, we used the metaphor of two baskets initially containing the same number of fruits, and then one of them being added fruits, thus revealing the difference between the numbers of fruits in the two baskets.

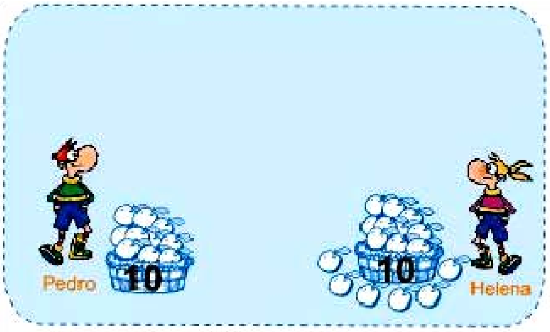

Figure 2: Comparison Diagram (Leite, Borba, Gomes 2008).

In the case of a word problem of change, we have the following example: "Helen had 8 oranges in her basket. She took 5 out of her basket and put them into Peter's basket. How many oranges does Helen have now?". The diagram (Figure 3) shows a dynamic relation, i.e. the initial number went through changes because of a direct or indirect action, causing it to either grow bigger or smaller. In this case, the variation involved an unknown number and a situation of decrease. In order to express this decrease in the original number through the diagram, we used a contrast between the fruit colours all through until the final state.

Figure 3: Change Diagram (Leite, Borba, Gomes (2008).

The use of temporality in this dynamic relation diagram requires the presentation to depict action through a time axis, thus allowing users to have the same kind of perception. In the case of Figure 3, first Helen appears with her apple basket, followed by Peter with his. Finally, the colour contrast reinforces the dynamic representation of the animation.

As for the equalisation category, we have the following example: "In Peter's basket there are 9 oranges, and in Helen's basket there are 6 oranges. How many oranges does Peter have to take out of his basket in order to have the same number of oranges as Helen?". In this case, the problem explores the invariable of a dynamic relation through which numbers are equalised from a comparison situation. For this particular example, we make use of a weighing scale, as shown in Figure 4, to suggest the invariable employed – i.e. the dynamic relation of comparison between the numbers and their equalisation.

Figure 4: Equalisation Diagram (Leite, Borba, Gomes 2008).

Like change word problems, equalisation word problems should include a time axis so as to fulfil the demands of the dynamic animation. In this case, we achieve this by showing an unbalanced scale, heavier on the side where there are more oranges. In addition to that, we have a dotted line indicating the state of balance/equalisation between both sides.

As for the messages about the kind of mathematical error, our intention was to indicate possible wrong procedures concerning the use of the algorithm. In this light, we have used objective and clear messages, so that users can understand them easily – such as "add them again" or "subtract them again". In these examples, users had already chosen the correct operation to find a solution, but needed to repeat the operation itself, i.e. check the number obtained. This is an indirect way of telling users to pay attention to which aspect has not been successful in their operation.

The four diagrams presented in Leite, Borba and Gomes (2008) demanded dynamic and static representations. Although the Conceptual Fields Theory has made clear through the description of invariants of each category and the referred study has run the experiment using temporality at the actions when they demanded statis representations, the Theory of Multiple External Representations emphasizes the need of dynamic and statical form of presenting as required by each problem.

The problems involving the categories of Combination and Comparation exploited phenomena with an statical representation. Although the study of Leite, Borba and Gomes (2008) has validated only um problem for each classification, the generalization of statical representation extends to the variations of them. The Multiple External Representations emphasizes that the use of statical diagrams is far more complex, once it is demanded to communicate all event in only one moment (Ainsworth, 2008)

The problems of Change and Igualization categories the use of dynamic representations was needed, since they involved invariants according to the Conceptual Fields Theory. The use of dynamic representations reduces the cognitive load, allowing learners to focus on their actions on the representations and its consequences in other representations. One sugention would be present the dinamic aspects in a image sequence.

6 CONCLUSIONS

For being based on the development of the individual, cognitive theories tend to contribute greatly to interface design.

While it is true that technology is present in the most varied areas of Education, and therefore could not be excluded from Special Education, on the other hand it is also true that the use of obsolete educational practices may distort and even compromise the design of an interface.

Another aspect one must take into account concerns the inclusion of deaf students in regular schools. Indeed, neither the students themselves – who probably used to attend so-called special schools – nor the teachers – who certainly were not trained to deal with students with special needs – were prepared to deal with this new situation.

Although the study conducted by Leite (2007) has already called attention to the need for an inclusive interface that respects all users' communication needs, in the present work we have stressed the relevance of help functions through diagrams.

Indeed, not only does this kind of symbolic representation through diagrams allow for a better understanding of the structure of the word problem, but it also helps reveal the meaning of the operations involved.

Even though it is often said that mathematical difficulties (particularly concerning the acquisition of concepts surrounding the notion of addition) have a lot to do with the organisation of algorithms (i.e. numeric calculations), the strategies adopted and the invariables employed by the students are also crucial elements that have a great impact on the acquisition of these concepts.

By using representations that employ the same concept, yet in a different, untraditional way (which in turn can be chosen by users according to their preferences), we have expanded the mathematical concepts in question. Indeed, by broadening the students' experiences of these concepts and the theorems-in-action, the mathematical concepts acquired become more mature and solid.

In this light, we are convinced that our study has brought about a new perspective in terms of what mathematical software should include. This contribution, we feel, have to do with both respecting all students' – hearing and hearing-impaired – preferences and their learning time to acquire a new concept. More importantly than that, our contribution is based on a theory that focuses on the acquisition of concepts.

As far as theories are concerned, another relevant aspect of the present study is the fact that the two theoretical frameworks chosen advocate the use of representations to complement the acquisition of a concept.

Indeed, the use of representations that complement each other benefit users greatly, because they help bridge the students' knowledge gaps in an interactive, fun way.

Furthermore, when it comes to the interpretations of images with a theoretical intent, these representations minimise the communication difficulties faced by deaf students.

In conclusion, then, the present study raised hypothesis about the contribution of cognitive theories to the help function of mathematical software. In this light, the next step would be to compare and contrast the representations currently used in the classroom to those recommended by the two theoretical frameworks used here.

REFERENCES

Austin, G. F. Knowledge of selected concepts obtained by an adolescent deaf population. *American Annals of the Deaf*, 120: 360-370, 1975.

Ainsworth, S., Wood, D., Bibby, P. Co-ordinating Multiple Representations in Computer Based Learning Environments. Brna, paiva & Self (Eds) Proccedings of The European Conference on AI in Education, Lisbon, 1996; 336-342.

Ainsworth. A. A functional taxonomy of multiple representations. Computers and Education, 33(2/3):131–152, 1999.

Ainsworth, S. Ainsworth, S. DeFT: A conceptual framework for considering learning with multiple representations. Learning and Instruction 16(3):183-198-2006.

Ainsworth, S. The educational value of multiple-representations when learning complex scientific concepts. In J.K. Gilbert, M. Reiner, & M. Nakhleh (eds.) Visualization: Theory and Practice in Science Education (pp. 191-208), New York: Springer Verlag.

Bull, R.; Marschark, M; Blatto-Vallee, G. SNARC hunting: Examining number representation in deaf students. *Learning and Individual Differences*, 15(3): 223-226, 2005.

Carpenter, T.P.; Moser, J.M. The development of addition and subtraction problem-solving skills. In: Carpenter, T.P.; Moser, J.M.; Romberg, T. A. (Eds.) *Addition and subtraction: a cognitive perspective*, páginas 123-146. Hillsdale: Erlbaum, 1982.

Carraher, T. N.; Carraher, D.; Schliemann, A. *Na vida dez, na escola zero*. 2ª edição. São Paulo: Cortez, 1988.

Leite, M. D.; Borba, R. ; Gomes, A. S. Contributions from the Theory of Conceptual Fields: help and feedback messages in educational software for deaf students. In: ICME - 11th International Congress on Mathematical Education, 2008, Mexico. Anais do ICME, 2008.

Kelly, R. R; Lang, H. G; Pagliaro, C. M. Mathematics Word Problem Solving for Deaf Students: A Survey of Practices in Grades 6-12. *Journal of Deaf Studies and Deaf Education*, 8(2):104-119, 2003.

Kelly, R. R.; Lang, H. G.; Mousley, K.; Davis, S. M. Deaf College Student's Comprehension of Relational Language in Arithmetic Compare Problems. *Journal of Deaf Studies and Deaf Education*, 8(2): 120-132, 2003.

Nunes, T.; Moreno C. Promoting deaf pupils' achievement in mathematics. *Journal of Journal of Deaf Studies and Deaf Education*, 7(2):120-133, 2002.

Traxler, C. B. The Stanford Achievement Test, ninth edition: National norming and performance standards for deaf and hard-of-hearing students. *Journal of Deaf Studies and Deaf Education*, 5:337-348, 2000.

Vergnaud, G. *Psicologia do desenvolvimento cognitivo e didáctica das matematicas*. Un exemplo: as estruturas aditivas. Análise Psicológica, 1(5):76-90. 1986.

Vergnaud, G. *El ninõ, lãs matemáticas y la realidad*. Problemas de la ensenanzã em la escuela primaria. México: Trilhas, 1991.