Design Practices for Multimodal Affective Mathematical Learning

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***Abstract*— In this paper we focus on interaction design for multimodal software in affective education, and provide a case study of our MADE (Multimodal Affect for Design and Evaluation) framework. We are considering the sensory modalities, affective and cognitive strategies and trying to solve mathematical learning difficulties such as lack of attention, distraction, stress or disabilities. Using a multimodal affective learning system will increase the encouragement in learning, and will help students develop grounded understanding of proportional equivalence e.g. 1/3 = 2/6.**

***Keywords*—affective technology; design process; education; human-computer interaction; multimodality**

I. Introduction

Human-computer interaction (HCI) and education can be modified with the help of affective and cognitive strategies, making construction of new concepts. New forms of interaction like speech and gesture are now becoming common, and interactions considering cognition and emotion are starting [1].

Multimodal user interfaces aim to recognize naturally occurring forms of human behavior and language. They feature two or more combined user input modes (multiple sensory modalities) and recognition-based technologies such as speech, gesture or touch in a coordinated manner with multimedia system output [2], [3].

An increasing interest in design perspectives in education could be noticed during the past decade [4]. Nobody disagrees with the role of affect in learning. Definitely teachers know that it plays a key role; a slight positive mood does not just make a student feel a little better but also encourages a different kind of thinking, bringing more attention, better decision-making, perception, and learning [5].

Building technologies that interact with learners to motivate, engage, and assist them in challenging new ways in learning is needed [6]. Interfaces that recognize the affective state of the learner (e.g., lack of attention, stress, distraction, etc.) and can adapt and respond to it are possibly to be perceived as more natural, efficient, and trustworthy.

Therefore, there seems to be a need for a new conceptualization of learning in multimodal interface design by increasing affective and cognitive concepts. As system designers, we wish to design an educational system and we need to answer the following questions: how might a framework be leveraged for designing educational software, and what are the methodologies to design it?

This paper presents a case study of a tool to support mathematical learning. Our affective design for multimodal education software presents the learner with affective strategies using 3D interaction, auditory and visual elements creating digital rules that synchronize with our physical intuitions to bring both worlds closer together, to improve interface design in mathematical learning. We have designed and implemented technology for providing students with an affective mathematical learning system in finding different math proportions (e.g., the sequence of equivalent proportions 1:3, 2:6, 3:9, etc.). Students will maintain a constant vertical distance between the levels of their two hands having different proportions. Figure 1 shows the prototype affective mathematical learning tool in use by a student.

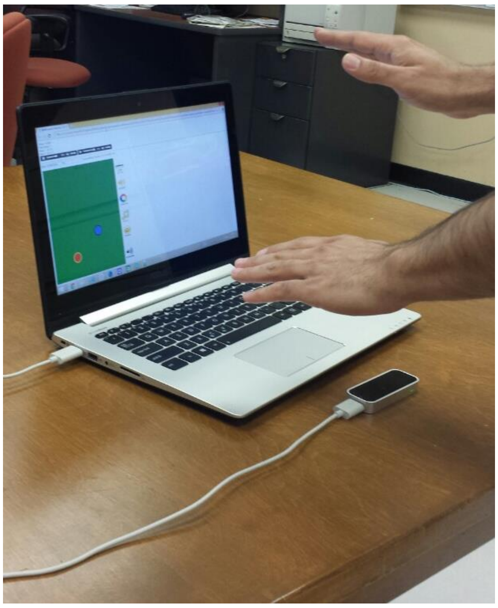

Fig. 1. The affective mathematical learning system in use by a student.

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II. Background

We reshaped the three domains of *Bloom's taxonomy* [7], a classification of the different objectives that educators set for students, and created a framework called *MADE* based on the taxonomy. Bloom's taxonomy breaks learning objectives for students into three domains that are cognitive (mental skills, knowledge), affective (growth in feelings or emotional areas, attitude or self) and psychomotor (manual or physical skills). We are considering the *multiple sensory* and *quasi-sensory* modality domains to help the affective and cognitive domains (see Table 1).

TABLE I. Comparing Bloom's Taxonomy with MADE Taxonomy.

Bloom's Taxonomy 1956	**MADE Taxonomy 2015**	
Learning domains:	**Learning domains:**	
Cognitive: mental skills (knowledge)	**Cognitive:** mental skills (Intellectual capability. i.e. knowledge, or 'think')	**Multiple sensory modality:** visual, auditory or tactile and **quasi-sensory modality:** e.g. embodiment, narrative or persuasion
Affective: growth in feelings or emotional areas (Attitude or self)	**Affective:** growth in feelings or emotional areas (Feelings, emotions and behaviour, i.e. attitude, or 'feel')	
Psychomotor: manual or physical skills (Skills)		

We are adapting two well-known design methods that are *Goal-Directed Design* (GDD) and *Usage-Centered Design* (UsageCD) to the MADE framework for a case study in affective educational software. The case study is based on the work of Howison, Trninic, Reinholz and Abrahamson [8]. They have designed a *Mathematical Imagery Trainer*, which is a mathematical learning system built to create opportunities for students in understanding the proportional equivalence concept of developing dynamical imagery as a cognitive level in an embodied-interaction environment [8], [9]. We have taken this concept and applied it to our framework to train new kinds of imagery for the concept of proportionality. They created an embodied-cognition system using the Nintendo Wii remote, but have not considered affect and multimodality. We are focusing on user interaction (UI) design work considering four different elements: affect, education, multimodality and software design, as no research has considered all these elements together. Examples of some research that has been done in each of these elements are:

- The circumplex model of emotion by Russell [10] (models of affect).
- Chang et al. [11] created a multimodal system using affective touch called *The Haptic Creature* (affect and multimodality).
- Hede and Hede [12] addressed learning that involves simultaneous interaction with multimodal media elements (multimodal design for education).
- Gelderblom and Kotzé [13] provide guidelines for designing technology for young children and what we can learn from theories of cognitive development (software design for education).

III. MADE Framework

MADE [14] is a theoretical HCI framework that looks at cognitive and emotional aspects. It has learning objectives, affective strategies, cognitive strategies and multiple sensory and quasi-sensory modalities for multimodal systems to support educational applications. It is used to help the learner to learn and engage more. The learning objective controls the metrics, affective and cognitive strategies, and the linkages. These strategies then inform the teacher, student and educational technology (see Figure 2).

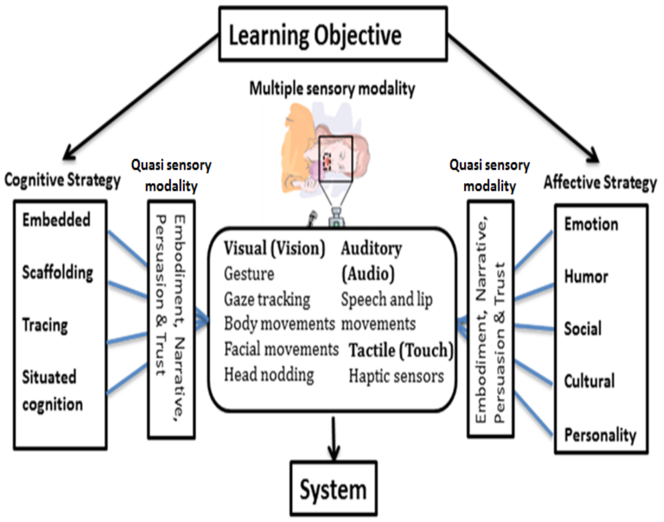

Fig. 2. The proposed MADE framework.

This framework is based on principles for multimodal design that considers affective and cognitive aspects of learners while interacting with a multimodal educational system. While interacting with educational software, a student can employ their sensory modalities (e.g. vision or audio); they may also need to employ some quasi-sensory modalities (e.g. embodiment, narrative or persuasion) while interacting with a supportive technology [14].

For instance, software that helps students learn about mathematics can have a cognitive and an affective strategy. We basically want to choose multiple sensory modalities that support both a cognitive strategy and an affective strategy. Some kinds of cognitive strategies suit some types of learning objectives. Cognitive strategy is informing what the learning is, and affective strategy is how to make it fun and help to bring enthusiasm, as a learner is emotionally involved in the learning process through multiple sensory devices.

When building educational software, affective and cognitive strategies are necessary, and might be used in role-play and identification. The role-play in this case study is an explicit situation established with teacher and learners playing specific roles, doing and saying what their character does in the classroom situation. Identification involves helping students develop grounded understating of proportional ratio.

IV. Design Process

We are using affective strategies because of students' cognitive difficulties in understanding mathematical proportions. We next illustrate the MADE strategy diagram for affective education and then show how we adapt the two design methodologies for affective multimodality education.

Figure 3 shows a specific version of the MADE strategy diagram for our case study: the mathematical learning system. The teacher actor, the student actor and the developer actor are associated with the diagram. The first and second use cases in the left side are "Move both hands to correct ratio" and "Moving one hand higher, bigger distance and ratio" (cognitive strategies). The affective strategy and the sensory modalities are "Play praising audios, happy music, show encouraging messages, use different colors, and icons during exercise" and "Use motion sensor device to indicate correct distance".

Each actor represents a role. The teacher has to come up with and *decide* the learning objective, the cognitive strategy and the affective strategy; he/she has a *monitoring role* with the system as well.

The developer has to take this model into the affective learning system. In the figure, the cloud is kind of a conceptual model, connected to the actual system; a top layer including the learning objective, affective strategy, cognitive strategy and the multiple sensory modalities.

In this study the learners have to make and keep the screen in different colors by moving their left and right hands in regard to a specific ratio and distance between their hands.

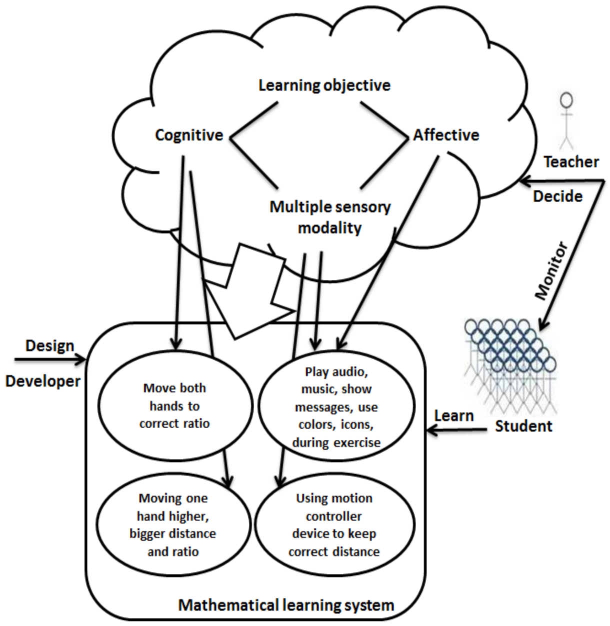

Fig. 3. The MADE strategy diagram specific to the mathematical learning system.

Now we describe the proposed adaptation of personas from Goal-Directed Design (GDD) for our mathematical learning system and the proposed adaptation of Usage-Centered Design (UsageCD) for affective education.

A. *Goal-Directed Design*

The first interaction design methodology we consider is GDD, created by Cooper et al. [15]. His GDD process results in a solid user model and a comprehensive user plan. It is a strong tool for answering questions like who are the users and what they are trying to accomplish, or how users interact with the system and how the system should behave and deal with problems they may encounter. It includes *personas*, which are user models that represent a class or type of user of a specific practical interactive design tools to create an outside view and help give new perspective to high-tech applications. The components of GDD are persona, scenario and end goal [15].

1) *Affective Personas*

To create a system to satisfy a variety of users we are using personas; models of the people who use the system; designing for specific types of individuals with specific needs. The personas do not describe real people, but are realistic and not idealized. They are rich descriptions of typical users of the system under development, which we as designers are focusing on [16].

For our multimodal affective educational case study, we use three personas, showing the emotional characteristics of the user; and considering affective and cognitive strategies with the help of the multiple sensory modalities to have a better learning environment. The personas are: one student whose parents would like him to become an engineer, one unconcerned student, and one more inclined student who has a reading disability (dyslexia).

a) 1st Learner Persona

It is hard for Oliver to learn mathematics. He has family issues and worries about the future, as his parents' desire is he be an engineer. Therefore, he is afraid of not being successful. By using a 3D motion sensor device in math course materials that provides embodiment, Oliver can see how to interact with mathematical software and learn it using his hands. By bringing mathematical principles closer to the user, it offers the opportunity to help bring science and mathematical learning to life, and tries helping Oliver in understating better mathematics, and reducing his fear and stress.

The teacher can encourage Oliver with affective strategies as well, such as humor and emotion, and using encouraging and praising audio, messages, icons and colors when correct ratios happen with the cognitive strategies.

The art of persuasion and scaffolding in learning maths can make more engagement and brings focus, precision, motivation and encouragement (see Figure 4).

a) 2nd Learner Persona

Badly designed interfaces are frustrating for Sarah in learning mathematics, who likes to listen to music, text messaging, dance and go clubbing. By having course materials with embodied interaction using motion sensor device for embodiment, and having happy audio, icons and colors results in learning that is more interesting with less distraction, and persuades the learner to change behavior attitudes.

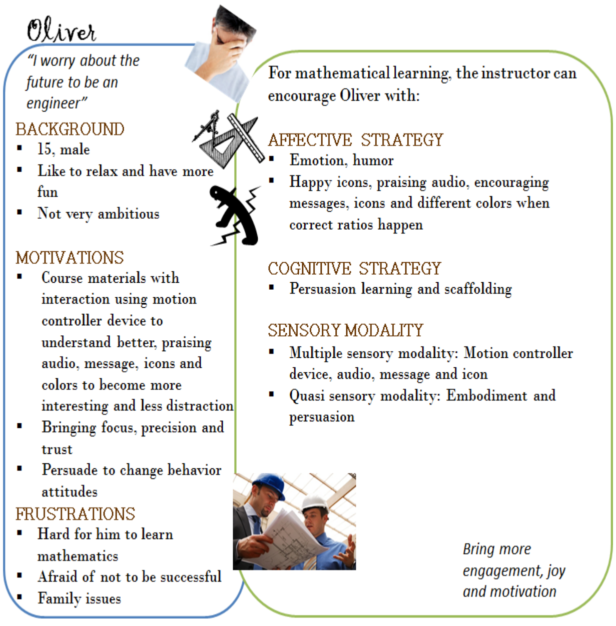

Fig. 4. 1st learner persona in mathematical learning system.

Affective strategies can be humor and emotion using praising audio, happy sound effects, different colors, happy icons and a pleasing interface when correct ratios happen. The cognitive strategy is embodied cognition. Sensory modalities are audio, music, icon, color and the motion sensor device. Quasi-sensory modalities are embodiment and persuasion. By considering these strategies the teacher can bring more engagement, attention, and pleasure to the learner (see Figure 5).

Fig. 5. 2nd learner persona in mathematical learning system.

b) 3rd Learner Persona

Mike has Dyslexia and has difficulty to read or interpret words, letters, and other symbols. With this motion sensor Mike has the possibility to control some course material just with a wave of his hands using this 3D modeling software. He likes to study; he is ambitious, but he feels shy in the social life, which is in this context a classroom environment. He has frustrations over expressing course materials in the classroom and he is not comfortable. He worries that students may make fun of him, and laugh about his misfortunes (superiority theory in humor [17]).

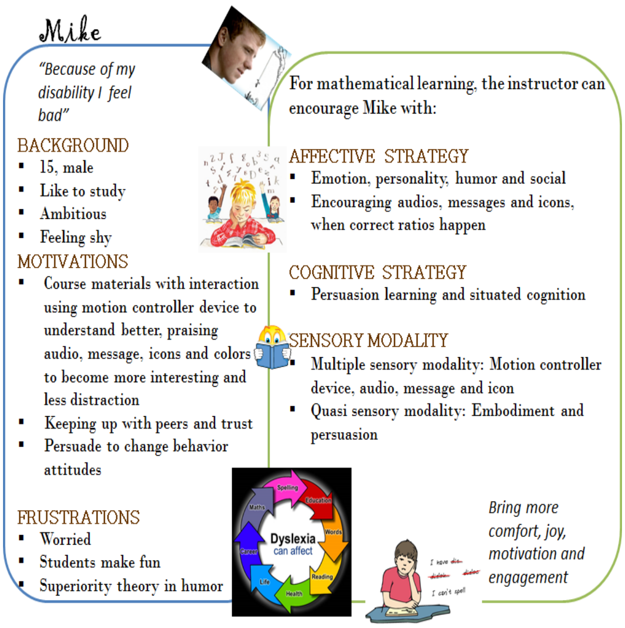

Fig. 6. 3rd learner persona in mathematical learning system.

The teacher can encourage Mike with affective strategies like emotion, humor, personality and social, encouraging audio and messages, and cognitive strategies, for example persuasion learning and situated cognition. By using multiple sensory modalities including motion sensing, audio, messages and icons, and also quasi-sensory modalities such as embodiment and persuasion, the teacher can bring more comfort and less stress to Mike (see Figure 6).

We now explain how to adapt UsageCD with learning objectives, affective and cognitive strategies and sensory modalities.

B. *Usage-Centered Design*

Usage-Centered Design (UsageCD) was introduced and developed by Constantine and Lockwood [18]. It is based on user intentions and usage patterns for user interface design; usage is how and for what ends software tools will be employed. It analyzes users' roles in relation to systems, employing abstract (essential) use cases for task analysis [18].

1) Affective Essential Use Case

Constantine and Lockwood developed *essential use cases* (EUCs) [18]; simplified, abstract, generalized use cases, to compensate for the limitations of both scenarios and use cases.

It captures the essence of the use case, which means you focus on *what* the result is meant to be and not *how* you achieve it. Therefore, the advantage of it is that we document "WHAT" the outcome of the use case is meant to be and leave it to the designer to come up with "HOW". Later, we have to see the different ways to implement it [18], [19].

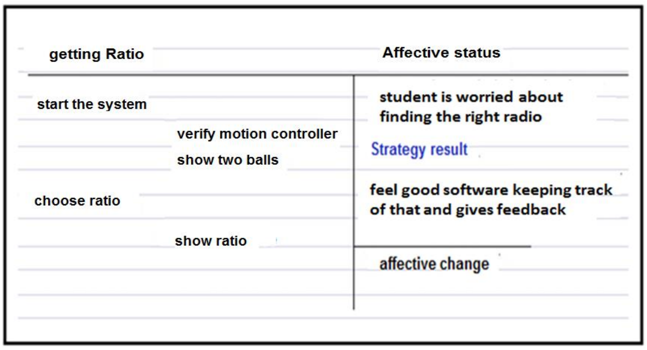

Fig. 7. An EUC card using the affective strategy.

Each use case has an affective objective. We add a part called the "*Affective sidebar*" to the EUC card, and have a column in the right side called "*Affective status*" (see Figure 7). Thus, the outcome of the use case basically should involve from the teacher, cognitive outcomes as well as affective outcomes [16].

Here our focus is education. With affective multimodal strategies that the mathematical learning system provides and transmits, the teacher can use different kinds of strategies such as affective messages, audio, and colors for the learning objective. The system's strategy is to persuade, motivate, and be encouraging in learning math, and brings a good feeling to the students to make them feel it is fun.

V. SAMPLE DESIGN

A. Mockups

For designing the mathematical learning interface, we used the Balsamic Mockups software (https://balsamiq.com/). Figure 8 shows the prototype layout, which is explained in the following:

- Top bar: provides us with the number of hands, shows position of each hand, ratio, affective feedback (audio, message and color), and if it is left, right or both hands detected above the motion sensor.
- Main window: in the main part of the screen there is a gray box with two circles representing each hand. And the circles move, as the student moves his/her hands up and down.
- Right side bar: on this side there are controls for the motion sensor, audio, icons, colors, music, and volume being able to select colors, audio, etc.
- Bottom bar: shows the area we interact with the system; the motion controller and keyboard.

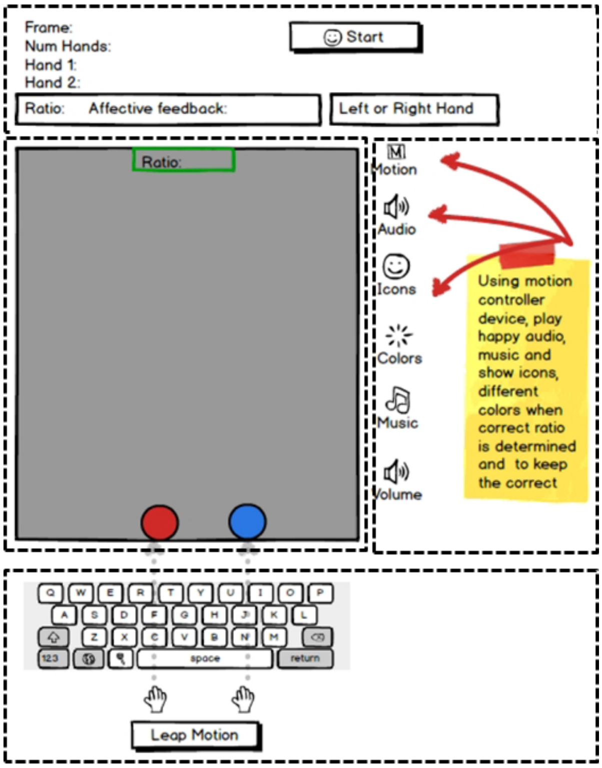

Fig. 8. Sketch-style wireframes for the mathematical learning system at the starting point.

Figure 9 shows when the system is being used, and it matches the ratio, there are affective feedbacks: the color turns into yellow, audio plays an encouragement sound by praising the user, and a message shows "Well Done!" above the screen box.

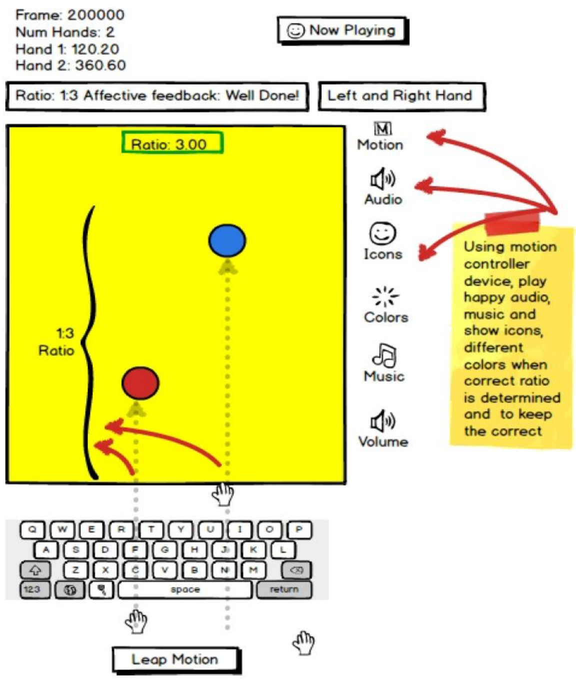

Fig. 9. Sketch-style wireframes for the mathematical learning system in use with ratio 1:3.

VI. IMPLEMENTATIONS

We now suggest what sensory modalities support the affective and cognitive strategies and how they could be built into a system. The multimodal system supports these two different parts, affective and cognitive strategies.

A. LEAP Motion Sensor

In this case study, we are using an ease of use, low-cost hand-motion tracking controller: Leap Motion sensor (https://www.leapmotion.com/) to design mathematical learning software using the MADE framework (see Figure 10). The Leap Motion device includes two cameras and infrared LEDs under a black glass. It enables the software to track two hands finger movements when they are moved over the device.

Several HCI research studies and applications have used this 3D controller as an input device for tracking accurate hand movements and to implement gesture-based and tangible user interfaces [20]. We are extending and considering a new application area: mathematics education.

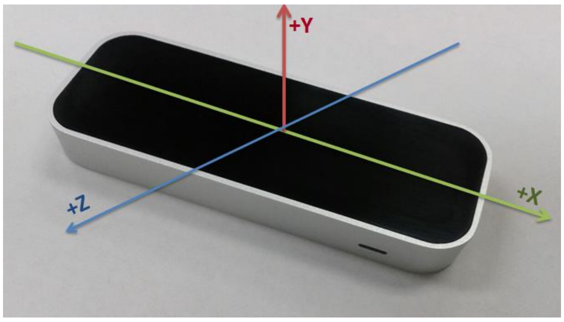

Fig. 10. The Leap Motion sensor.

Figure 11 shows a snapshot of the mathematical learning environment at the starting point. For developing the software we used JavaScript and Raphael graphics library (http://raphaeljs.com/).

At the start, we show how a user is interacting with a Leap Motion sensor device using his/her hands moving them to fix 1:3 proportional progression having audio and background color to indicate their accuracy, and to have an emotional influence on the learner.

In Figure 12 a student who has moved both hands up and down along the screen (does the sequence of equivalent proportions 1:3, 2:6) has achieved the ratio 2.96, and gets affective feedback: an audio and a message saying “Well Done!” and the background screen changes to yellow.

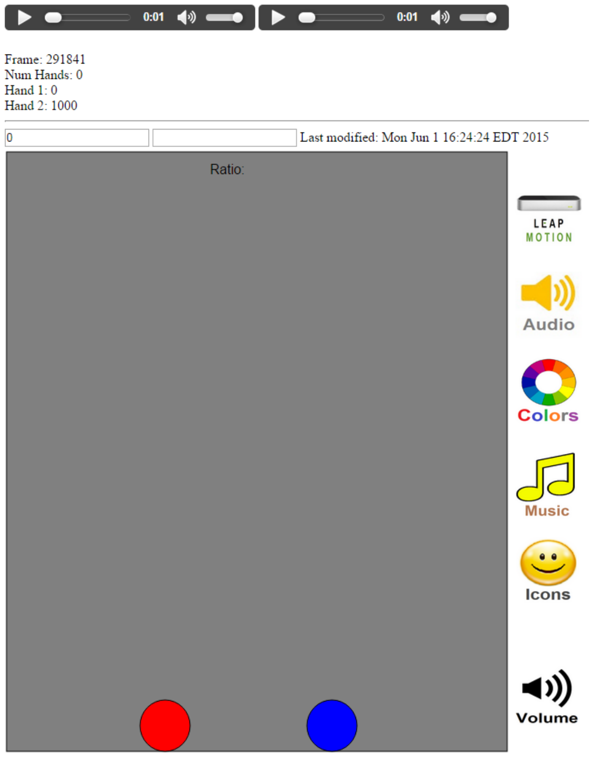

Fig. 11. At the starting point the circles representing the user hands are at the bottom, and the background color is gray.

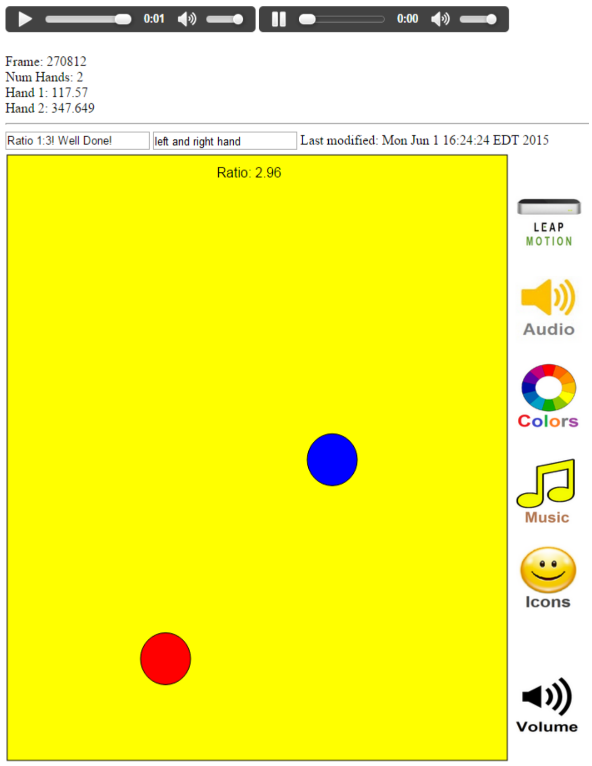

Fig. 12. By moving the right hand higher searching for equivalent proportions 1:3 and 2:6; a ratio of 2.96 is reached, resulting in affective feedback of audio, a message, and screen color change.

VII. CONCLUSION

This paper focused on a case study on UI design and implementation for multimodal software in affective education. In particular, the purpose of this paper was to describe a design approach for an emotional multimodal education case study considering the affective and cognitive strategies. The ability to communicate emotionally and cognitively plays an essential role in HCI and education. Our main claim is that issues of affect in multimodal software have not been addressed for software design for education. The challenge is how theoretical models of HCI can inform multimodal affective design in learning. For the design guidelines, we adapted well-known design methodologies to the MADE framework, and we proposed the adaptation of personas from GDD and propose adaptation of UsageCD and essential use cases for multimodal affective education.

We applied the proposed MADE design methodologies to mathematical learning case study that investigates the use of affective learning in multimodal software, trying to increase the engagement in students with learning materials.

In future we plan to do a user study and applying the usability inspection methods we proposed [21] on this case study and perform the study with teachers and learners. It is hoped that the design methodologies applied in this study may encourage educators to consider these methodologies in a teaching environment for the purpose of learning mathematics.

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