Marker-based augmented reality: Instructional-design to improve children interactions with astronomical concepts

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ABSTRACT

This paper presents the instructional-design of an augmented learning environment named AIBLE-HELIOS® that is targeted at teaching astronomy to children. This environment takes benefit of Augmented Reality (AR) and tangible interaction to stimulate an active and learner-centered approach to scientific problem solving. This approach follows the pedagogical principles of the Inquiry-Based Sciences Education (IBSE). Technical specifications and the design of the application have been based on didactical principles. It is intended to children of 8 to 11 years old in formal education. HELIOS was tested in-situ, i.e., in real teaching conditions with pupils (grades 4-5) from two primary schools. This user study confirms the design assumptions that influence children's interaction with contents during sciences courses. The analyses of the children's interactions with the system as well as learning indicate that HELIOS supports children in their investigations. Moreover, it provides some new information on children's interactions possibilities that will be taken into account in future versions. All these parameters contribute to the understanding of the ways through which AR can be used in formal teaching curricula in K-12 schools.

Categories and Subject Descriptors

H.5.2 [User Interfaces]: Interaction styles, User-centered design; K.3.1 [Computer Uses in Education]

General Terms

Design, Human Factors.

Keywords

Instructional-design, Child-Computer Interaction, Inquiry-Based Sciences Education, tangible interaction, K-12, User Experience

IDC '15, June 21 - 25, 2015, Medford, MA, USA
© 2015 ACM. ISBN 978-1-4503-3590-4/15/06…$15.00
DOI: http://dx.doi.org/10.1145/2771839.2771842

1. INTRODUCTION

Children and many adults have difficulties in understanding contemporary scientific explanations of elementary astronomical phenomena (e.g. [1-6]). Even if young children are highly motivated by sciences topics at school, classical pedagogical supports (book, web site, physical models…) are still insufficient to overtake misconceptions.

To face these difficulties, we explore a pedagogical environment based on augmented reality (AR) and tangible interactions. Indeed, compared to pure digital virtual tools such as virtual simulations, AR allows user experiences that opens promising opportunities in the educational domain [7]. Since Billinghurst's initial work [8], many studies were conducted to implement AR in formal education. Mainly focused on higher education, most of them were in fields appealing 3D modeling and spatial perception such as architecture, chemistry, mathematics, anatomy or physiology (e.g. [9-12]). Augmented Reality (AR) is certainly one of the most promising technologies to reach beyond the traditional interactions with digital environments in K-12 education [13]. For numerous teachers, AR tools seem to be the best environments for providing relevant feedback and for simulating complex phenomena [14, 15]. Recent studies concerning design of AR learning environments focused on scripted or gamified AR environments [16], or on the influence of professional factors [17]. They all concluded that AR could be well aligned with situated and constructivist learning theories by influencing motivational dynamic principles. However, AR implementations in primary school are uncommon [18-20].

AR could have the potential of enhancing certain areas of learning. However, it is important to remember that learning is not a simple process of transfer of knowledge from a teacher or a technology to an individual. To be integrated in the classroom, an AR environment need to be built as a pedagogical support adapted to the nature of knowledge, to children development and institutional constraints. Currently, very limited AR supports (e.g. [21]) are designed with a specific regard to didactical sciences principles.

This paper presents the instructional-design of HELIOS (Hybrid Environment to Learn the Influence of Sunlight), an Augmented and Inquiry-Based Learning Environment (AIBLE). This environment is focused on astronomical phenomena for primary school children. Its design process is user-centered and is intended to be iterative. Moreover, we describe a user study we conducted in real conditions to evaluate the influence of our first design choices on children interactions during problem solving and learning.

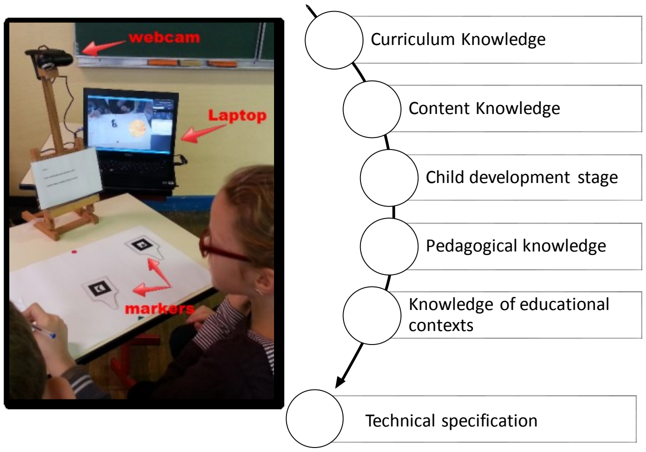

Figure 1: HELIOS environment (left) and didactical principles involved in its technical specification (right).

2. HELIOS INSTRUCTIONAL-DESIGN PRINCIPLES

To design AIBLE-HELIOS®, we propose to use the same principles as those used to construct a traditional pedagogical situation, while integrating new technologies. Didactics of sciences aims at providing design principles for teaching scientific concepts in a way that makes it understandable to children. This first prototype of HELIOS involves some of those principles in its design (see Figure 1). Therefore, we mobilized the structure of scientific knowledge as well as learners or teachers' psychologies, cognitive and child development, pedagogical principles and institutional constraints. Each step will be described hereafter.

2.1 Curriculum, Content Knowledge and child development stages:

Astronomy is taught in school worldwide. However, France is among the few countries which have integrated astronomy in primary levels [22]. The French 4-5 grades curriculum is centered on the solar system, the astral motions (satellite or heliocentric revolution, rotation) and the influence of the sunlight on day/night alternation, Moon phases' changes and seasons, as well as lunar or solar eclipses. Therefore, astronomy at primary school mobilizes knowledge and skills from optics and geometry. For 8 to 11 years old children, astronomy is certainly one of the most complex topic to learn within the French sciences curriculum. Consequently, it is important to take into account the knowledge structure in order to provide a scientific learning model that is proper to the specificity of pupils' abilities.

To understand astronomical concepts, children have to construct the causal relationship between the light source position, the relative position of the different asters and their relative spatial positions (revolution and rotation of aster induce modification of the lightening zone) and geometrical shape of each aster (lightening a spherical shape produces specific shadows shapes).

Vision is the first sensory modality for sensing the spatial layout of an environment [23]. However, the geocentric position of children's observations and the large scale of the phenomena induce barriers to the understanding of astral motions and related influence of Sun position on shadows formations on Earth and Moon. Children have to construct a mental image of spatial relationships from an allocentric point of view to contradict their ego/geocentric one. This astronomical problem involves projective skills and spatial cognition. Most of them are similar to tasks such as way finding using a map [24].

However, 8-11 years old children cannot access large-scale spaces to observe and solve these types of astronomical problems. Moreover, at this stage of development, most of the children still need concrete, topological information to construct mental images [25, 26]. All the evidences that structure the adults' environmental perception are not totally developed among children from grades 4-5. Children have to use topological spatial relations (properties of single object or configuration) before being able to use projective or Euclidean representations. Task performance in children spatial cognition closely depends upon the materials used: *"the greater the abstraction of material, the more difficult would be the task"*. [24].

Technical specification:

Taking into account all of these requirements, the design of AIBLE-HELIOS® was oriented toward new 3D technologies and specifically Augmented Reality. Our hypothesis was that AR could provide children with important visual supports to spatial cognition and then enhance their learning as exposed in previous studies (e.g. [27]). Therefore, in the HELIOS augmented environment, Sun, Earth and Moon appear realistic as they are represented using textured 3D spheres (textures were obtained from space images). Virtual Sun, Earth and Moon are associated to specific tangible markers than can be easily identified. This makes coexisting virtual information and the real environment. The light properties are taken into account and self-shadows of Earth and Moon are directly produced by an omnidirectional light source associated to the virtual Sun. Different visual guides are proposed to support learners (see Figure 2). The rendering of the 3D objects is done with OpenGL.

Dashed-lines are drawn between the center of the Sun and the centers of the Moon and the Earth. This helps the user to understand the three celestial bodies' relationship (see Figure 2-a). Additionally, an optional viewport can be added to the main window (see Figure 2-c). This viewport displays the viewpoint that an observer would obtain if he or she were looking at the Moon from a ground-based position on the Earth, highlighted by a small character (see Figure 2-b).

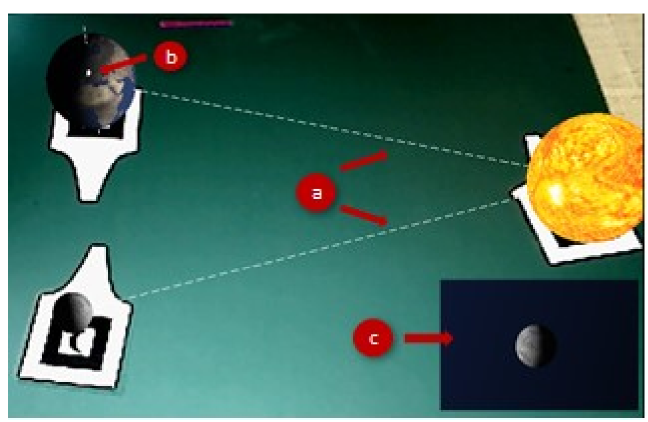

Figure 2: Example of first person perspective of the AR environment. Visual guides support learners: (a) dashed-lines between bodies' centers (b) a terrestrial observer (c) Viewport showing the terrestrial observer's view in real-time.

It allows children to relate the Moon observed from the Earth, directly to the allocentric view. Moreover, it is possible to adjust the viewing scale, the latitude and longitude position of the observer using keyboard commands.

2.2 Pedagogical knowledge

The success of the learning process in an educational system depends on how the system presents the domain knowledge to the learner according to the learner's progress. To enhance the efficiency of science learning, especially in astronomy [28, 29] Inquiry-Based Sciences Education (IBSE) pedagogical principles could be used [30, 31]. The French education system promotes IBSE which is actually internationally recommended for sciences education [32-34]. It is a learner-centered/constructivist pedagogy [30, 31]. It involves heuristic strategies to help learners acquire new concepts by themselves. As for every learner-centered pedagogy, students are encouraged to take active control of their learning. It allows children to express and support their ideas, make predictions, hypotheses and test them by conducting experiments. However, very few studies have explicitly considered these inquiry-based learning principles in their design-based approach (e.g. [35-37]).

In IBSE pedagogical situation, learners should investigate and manipulate in order to become conscious of complex phenomena, change their misconceptions and construct scientific knowledge [29]. Manipulations in astronomy are naturally impossible. Those manipulations can only be conducted with models.

Technical specification:

Designing an AR environment that takes into account IBSE pedagogical principles requires pupils to experiment by manipulating and interacting physically with the content. Marker-based AR is well tailored to Inquiry-Based Sciences Education (IBSE). The markers play the role of tangible props that can be manipulated by the learner. Thanks to the AR technology, these props are augmented with digital information displayed on the screen. In HELIOS, ARtoolkit is used to track the markers.

HELIOS, is thus qualified as an Augmented and Inquiry-Based Learning Environment (AIBLE). It combines the possibilities of AR with the intuitive physical manipulation of tangible markers, where both virtual and real objects can co-exist and interact in real time. With AIBLE-HELIOS®, the virtual celestial objects can be freely moved. Users can investigate and find by themselves the origins of the Moon phase's evolution, alternation of day and night, seasons or Moon/Sun eclipses. They can test their own hypotheses and they can directly visualize the results provided by the augmented model. Moreover, it is possible to adjust the level of difficulty so as to take into account the heterogeneity of children's abilities. For example, it is possible for children or their teacher to choose, using a keyboard command, only one marker to visualize the Moon orbiting around Earth instead of the two independent markers such as in the classical situation.

2.3 Knowledge of educational context.

Before assessing HELIOS directly in the classroom, we wanted to know more about the acceptability of these technologies by young users. Indeed, one may argue that the learning improvement could be due to ICT-support motivation effect. However, for young pupils frequently exposed to new technologies, it seems that attractiveness of the technology does not play a primary role. Instead, the contents and its challenging goals seem to be the main cause of improvement. In order to confirm this, we asked children to complete an ICT-use questionnaire. This survey was completed by 126 pupils coming from three schools before they participate to user-studies and learning improvement evaluations (see Section 3). This survey indicates that 99% of them use a personal computer every day, 82% own handheld gaming devices or mobile devices and 43% have already use AR (e.g. 3DS games, augmented book, augmented website…). Integration of tangible augmented reality technology would not be a problem for children with regard to these results.

Beyond AR children acceptability, there are a lot of barriers to technology integration in K-12 schools. One of these is certainly the lack of financial resources and the beliefs, the gap of knowledge, and the lack of specific technological skills of the teachers [38, 39]. In astronomy teaching, classical physical models promoted by textbooks possess a large part of IBSE parameters (i.e. manipulation possibilities, physical representation of celestial bodies, investigation possibilities...). However, compared to AR models, these traditional physical models that need a dark environment are limited to a simple configurations. The symbolism of the visual representation and the complexity of the interactions are not conducive to scientific learning [40]. Despite this, those types of model are generally used in primary classes because they are nearly free, and easy to use by teachers.

Technical specification:

It is absolutely necessary to take into account this professional reality in order to encourage the integration of a new digital support in the classroom. Thus, we have designed a cheap, quick-to-install and easy-to-use AIBLE that can be used in small workspaces and ordinary light conditions (see Figure. 3). It basically consists of a fixed webcam, a laptop computer and three printable markers (see Figures 1, 2 & 3).

3. EVALUATION

3.1 Method

We conducted empirical studies over 126 young French learners from 3 different French primary schools and in respect with parental and institutional agreements. These studies were conducted in-situ and in real teaching conditions. We focused our analyses on the following astronomical problem: *"Why are Moon phases changing daily?"*. The use of HELIOS was included in an IBSE pedagogical sequence, which was strictly identical in all schools (See Table 1).

An exploratory study was first conducted over 39 children from one of the three schools. We compared the AIBLE model to a physical one to estimate the efficacy of HELIOS on learning. This previous study, presented in a French conference [40], was based on pre and post-tests evaluations and analyses of pupils' workbooks. It concluded that only AR users developed scientific conceptions of the explored astronomical phenomena. It showed evidence that this AIBLE improved and enhanced astronomical learning and conceptual changes significantly compared to classical learning support. These initial results motivated the further development of this AIBLE.

The purpose of the current paper is to verify design hypotheses about the interaction possibilities offered by HELIOS. In order to characterize how the HELIOS users interact with the device and the concepts, we focused our analysis on a heuristic evaluation.

3.1.1 Participants

Usability testing was conducted over 87 children from two different schools. We aimed at qualifying the interaction of children when manipulating HELIOS. All the learners were recruited from grades 4 and 5 in two French schools (see Table 2). 49.3 % of them were male. Students' age varied from 8 to 11 years old (M_{age} = 9.16 SD = 0.96).

3.1.2 Setting and procedure

This study took place in the pedagogical sequence structured in 6 steps and during 6 non-consecutive days, each separated by one week from Step 2 (see Table 1). Each step lasted 45 minutes on average. Pupils' interactions were videotaped. The research team conducted the pedagogical sequences.

According to IBSE principles, Steps 2 and 3 aimed at assessing the children's preliminary knowledge (Pre-tests) and the way they talk about their hypothesis on the origin of Moon phases observed during the previous month (Step 1). The pre-tests and so post-tests were conducted in three ways: a written test focused on astronomical knowledge; graphic representations and oral interviews of their conceptions and hypothesis.

During Steps 4 and 5, the children had to improve their conceptions by conducting investigations using HELIOS. During these, the AR system was set up in the classrooms to perform the exercises. A Logitech QuickCam pro 9000 webcam was connected to the laptop computers running under Windows 7 or 8 (see Figure 1). Pupils using HELIOS have worked in two-person teams (one team was a trio), as classically done in learning sessions using computers. The Step 6 of the pedagogical sequence was dedicated to post-tests, similar to the pre-tests. As observed in the exploratory study [40], pre and post-test assessments indicate that HELIOS has improved learning and it allows overcoming misconceptions (see Table 2).

Table 1: Pedagogical objectives of the sequence based on IBSE principles including time for manipulations (Steps 4 and 5)

Step	*Pedagogical Objective*
1	Contextualization of learnings: Have a personal observation of the evolution of Moon phases
2	Diagnostic assessment of conception: Situate his/her observations in the didactical context and verbalize his/her conception of the phenomena.
3	Problem statement: Discuss his/her conceptions to make them conscious and formulate hypotheses.
4	Problem-based student investigations: Understand, after investigations, the origin of the shapes of Moon. First learning review
5	Problem-based student investigations: Understand, after investigations, the physical origin of the evolution of Moon phases. Second learning review
6	Reinvest learnings and evaluate acquisitions Summative evaluation

Table 2: Characteristics of the 87 study participants and pre- and post- tests of learning results

Pupils nbr		
French grades	Total	87
	Girls	50,7%
	Boys	49,3%
	Age mean (ED)	9,16 (0,96)
	CE2	27,5%
	CM1	40,6%
	CM2	31,9%
Pre-test results	Not Acquired	72,4%
	Under Way	17,2%
	Acquired	10,3%
Post-test results	Not Acquired	16,1%
	Under Way	39,1%
	Acquired	44,8%

The usability testing results was focused on Step 5. During this step, the complexity degree of manipulation and problem solving was important. Children were asked to reconsider their conceptions from the origins of 4 different Moon phases (full Moon, new Moon, first quarter and waning crescent).

Children had to test their hypotheses and spatially arrange Sun/Earth/Moon markers to recover their relative position in the "viewed from space" point of view (allocentric view) in order to find the 4 Moon phases as viewed from Earth (geocentric view). Pupils worked in relative autonomy. During these steps of inquiry, the teacher exposed the first principles of interactions, explained the instruction of the problem, and acted as resource person if necessary.

Our analyses are based both on video recordings analyses and digital logs of the markers motions. Video recordings were separately visualized and coded using The Observer XT® 11.5 (Noldus, Info Tech, Wageninen, The Netherlands). Coding was based on a behaviour grid consisting of 4 behaviour classes: i) task involvement (duration of children activity, dropout rate, and amount of aid claimed…); ii) verbal behaviour, iii) gestural and iv) visual interactions typologies (amount, nature…). With the help of The Observer, behaviour frequencies and duration were computed.

3.2 Results and discussion

The duration of student activities was approximately the same (30/35 minutes) for each session; all the pupils started their investigations quickly and did not hesitate to request the teacher (about 5 to 7 times per inquiry-based sessions). In each pair, pupils frequently exchanged their points of view and ideas. Formal verbal exchanges were generally closed to the time of writing answers on their workbooks. All pairs but 5 succeeded in solving the astronomical problems after testing their various hypotheses and after discussing together their protocols and results. Investigations dropouts were very limited.

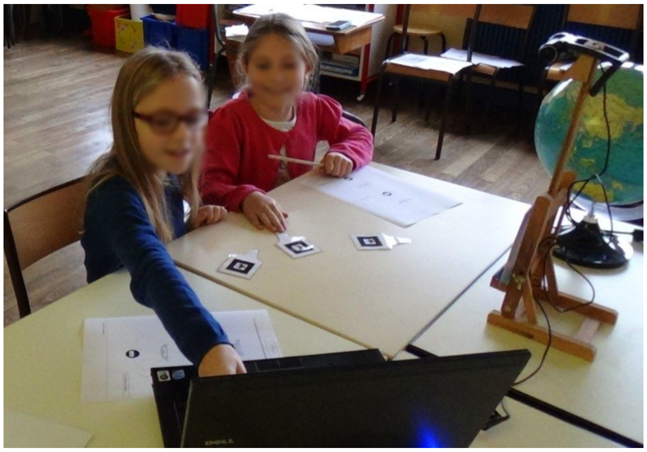

Figure 3: Example of typical children interactions with the system.

3.2.1 Children interactions with the system

100% of the children identified spontaneously the asters and promoted the realism of the 3D model. Using AR modeling, celestial bodies identification became obvious for the pupils. This factor is not trivial for the child.

However, 32,2% of the children complained not to be able to modify, using keyboard commands, the scale of the virtual asters and 49,4% not to be able to move the observer anywhere on Earth. Children largely promoted tangible interactions instead of keyboard use. The next version of our system will take this information into account.

All pairs manipulated the markers without looking at their hands. They continuously gazed at the monitor during 86% (SD 4.9) of the test duration (see Figure 3). Video analyses indicated that their visual attentiveness was related to the distinctiveness of objects or consequences of the phenomena inquired. The HELIOS visual feedback mobilized their perceptive tasks. Moreover, physical environment layouts were referred, gesturally (see Figure 3) or orally, by 42 children to explain/describe spatial positions of virtual spheres; e.g.:*"Put the Earth near the camera!"; "Why do you push the Sun window toward?"*; *"Earth is in the center of the table because Moon rotates around"* etc. Thus, using AIBLE-HELIOS, children benefit from physical spatial indicators used as landmarks during astronomical problem solving. The AR dashed-lines (see Figure 2-a) that join the bodies' centers are frequently promoted as spatial indicators. 31 pairs orally indicated that they provide geometrical information of celestial bodies relative to their spatial positions and help pupils place the Moon around the Earth, while taking into account the Sun position. This study confirms Shelton's observations [27] conducted with adults. Through the co-existence of virtual and real objects, AR provides visual tools to children, which are essential for success in spatial tasks mobilized by astronomical contents. Perception of natural perspectives (vanishing lines, depth, distances etc.), augmented by virtual lines, seemed to help children to rapidly encode spatial layout. An eye tracking study in future works could be conducted to verify this assumption.

The users systematically used the viewport to verify their hypotheses. As expected, real-time view of the ground based observer facilitated and supported users' investigations. 32 pairs of pupils orally indicated that their direct manipulations could be immediately related to the visual answers, providing assessments of hypotheses tested.

Using this AR viewport, children observed directly and easily the differences between egocentric versus allocentric perception. Moreover, children find meaning in their manipulations, which promoted awareness of scientific explanations. Our design choices therefore contribute to spatial abilities development, perceptive tasks mobilization and transitions from an egocentric perception to an allocentric one. HELIOS appears to be a tool of scaffolding for spatial cognition and problem solving skills.

The simple mobility of the virtual celestial objects was strongly promoted (93.1% of the pupils). Almost all children spontaneously used tangible markers for problem solving. Only 3 pairs of pupils waited for authorization before starting their investigations due to a lack of confidence. Children worked together towards the same purpose (e.g. one moved Moon markers or terrestrial observer and the second provided screen control) and manipulated the system alternatively. AR occlusions did not really interfere with perceptive tasks mobilized by problem solving. However, 36.6% of the users encountered problems with losses of the virtual celestial bodies due to markers' occlusions by hands or fingers. 23% of the pupils expressed irritation signs due to the wrist movements that are required to rotate the markers. 13% of them had difficulties, but only during the first 5 minutes, in understanding the marker orientations in the webcam frame of reference. Future works should focus on these problems.

The majority of the investigations mobilized gestures associated with visual interactions previously described. However, pupils rarely lifted up the markers (13.8% of the pupils). Users' gestures were situated in the camera's field of view, on the table plane and were thus limited. Compared to experiments with physical models [40], this limited working area reduces the locomotion efforts that are required and, consequently, it decreases the risk of cognitive overload. As expected, pupils used mainly circular motions or rotations for moving markers on the table plane, but linear motion were also frequently observed.

3.2.2 Children interactions with contents

All pupils initiated gesture strategies for solving problem on their own initiative. The AIBLE afforded intuitive manipulations. Markers motions reflect hand movements. As such they can serve as evidence of underlying representations in memory and of the processes by which such representations are derived and used.

As stated above, children could visually study the physical layout. They were sensitive to spatial distribution of virtual objects and could adopt strategies that both maximized, in their opinion, the chance of finding the answer and minimized the search efforts. They could plan and anticipate their manipulations and construct mental images using their own significant gestures. Strategies based on predictions, sampling, trail and errors prevailed. They are evidences of children explorations in novel environment and scientific contents.

The six-dimensional motions of the markers in the camera coordinate system were recorded during all pupils' working sessions. The 3-D paths of the center of the markers could then be graphically represented to help analyzing the gesture strategies during problem solving.

Five different problem solving strategies, representing children's hypotheses and their metacognitive mental models, have been identified (see Figure 4).

- Strategy A: This strategy was used by a total of 28% of pupils' pairs (Figure 5). After a few movements aimed at deciding the markers positions, the Sun and Earth markers were considered as fixed. Moon marker was placed with high accuracy in order to reach optimal positions. Mistakes were infrequent: They were essentially due to confusions between waxing and waning crescents (see Figure 4 strategy A – red arrow). Children using this strategy were generally able to rapidly correct themselves. This strategy is related to faster performances and with mental schema allowing pupils to make changes early. This strategy can be associated to highest expertize in astronomical problem solving resulting in lower mental effort during task performance [41].

- Strategy B: This strategy was used by 30% of pupils' pairs. The Sun and Earth markers were considered as fixed after many trials.

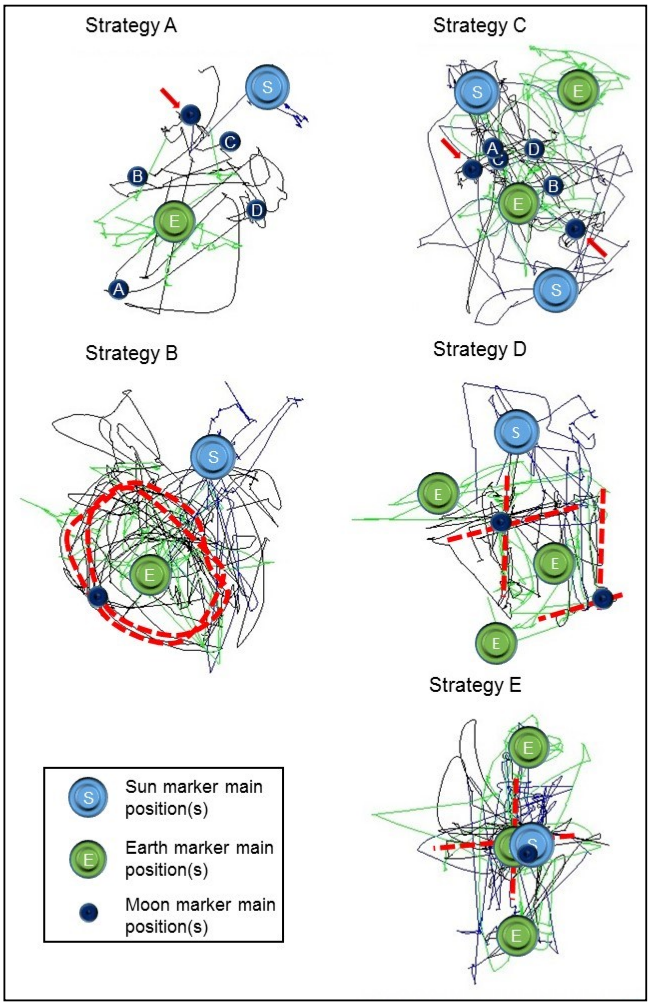

Figure 4. Five different problem solving strategies were identified from the markers motion log. Moon marker is symbolized by a dark-blue coin, associated to a capital letter if it corresponds to an expected response (A) = Full Moon; (B) = first crescent; (C) = new Moon and (D) = waning crescent. Red arrows indicate pupils' mistakes. Dashed-lines indicate main Moon marker movements occurring repeatedly.

Figure 5. Distributions of the study participants according to their strategy types promoted during investigation using HELIOS

With the strategy B, pupils processed with methodical circular movements of the Moon marker around Earth to reach one of the 4 Moon positions expected. Pupils used groping and significant gestures for Moon revolution trajectory.
This strategy should not be associated to expertize. Every learner used frequently the visual feedback provided by the egocentric viewport. However, it indicates that astronomical principles are integrated during the problem solving task.

- Strategy C: This strategy was used by 12% of pupils' pairs. Learners used triangulation principles. Sun, Earth and Moon markers were simultaneously moved, taking into account the relative positions of each other.
  Users selected optimal positions by using linear motions. Mistakes were of the same nature as for strategy A (see Figure 5 strategy C – red arrow) though more frequent.
  This strategy could be associated to a mathematical problem solving approach. It reflects the understanding of a part of the scientific knowledge by learners: ray optics. Pupils used significant gestures to find light trajectories.

- Strategy D: This strategy was used by 16% of pupils' pairs. In the same way as for strategies A and B, the Sun marker was considered as fixed according to astronomical conceptions. However, Earth marker and Moon marker were moved using linear motions as in mathematical conceptions (Strategy C). Pupils used groping and significant gestures for geometrical trajectories. This strategy could be assimilated to the C one. However, the confidence level on hypotheses and/or movements linked to problem solving was lower. Even if learning was enhanced, astronomical and optical knowledge stayed under development.

- Strategy E: This strategy was used by 14% of pupils. Sun, Earth and Moon markers were moved from the same central point without clear goal. In this case, gestures strategies are arbitrary. Thus, pupils proceeded by trial and error, without any hypothesis neither for the results nor for the problem solving strategy. Almost half of the pupils who did not take benefits of this AIBLE to enhance learning have used this strategy. This type of problem solving task is currently observed when meaning are not linked to relationship of similarity or other relationship from previous knowledge.

4. CONCLUSIONS

HELIOS facilitates children's perception of astronomical objects. This study confirms that co-existence of virtual and real objects lowers abstraction levels of young learners by providing concrete spatial and scientific references. Easy perception of concretes indicators facilitates spatial information encoding and assesses learning of spatial layout of this environment. HELIOS provides children with visual tools essential for success in spatial tasks and so upgrades awareness of scientific explanation. Moreover, visual interactions promoted by AR develop spatial strategies skills, which could be re-invested in problem solving tasks. Children using HELIOS are able to plan their own mental processes and to engage intuitive manipulations. These tangible interactions contribute to spatial abilities development, which are required to construct scientific conceptions of astronomical phenomena.

In this study, markers motions, reflecting hand movements, served as evidence of underlying representations in memory and the processes by which such representations are derived and used. 5 different problem solving strategies, representing children's hypothesis and their metacognitive mental models, were identified. Pupils, who able to use their own significant gestures, can concretely, simply, and intuitively test their conceptions about astronomical/mathematical knowledge and about expected phenomena. Pupils control their investigation to solve complex problems and have the possibility to construct scientific explanations using their own mental schema. HELIOS, as expected for an inquiry-based environment, really allows heuristic investigations, which fosters consciousness of the origin of astronomical phenomena. Then, this AIBLE is a tool for scaffolding and an epistemic support, enabling learner to really interact with concepts so as to overcome their conceptions and, to construct scientific knowledge.

Even if we have to enhance the usability of markers and keyboard commands, all of these results confirm the technical choices induced by a design based on didactics of sciences. AIBLE-HELIOS® allows learners to put forth their own strategies and encourages them to construct their own understanding. This way, AIBLE-HELIOS® enables learners to interact with contents.

5. ACKNOWLEDGMENTS

AIBLE-HELIOS® development is financially supported by the SATT Grand-Est. We want to thank the Ministry of National Education school inspectors for allowing us to conduct studies in classrooms. The authors thank the schools, their teachers and all the pupils who took part in this study. And finally, we want to sincerely thank Gilles Simon for his collaboration at the early stage of the development of AIBLE-HELIOS®.

6. REFERENCES

[1] Bryce, T.G.K., and Blown, E.J., 2012, The Novice-Expert Continuum in Astronomy Knowledge, *International journal of science education*, 23, 4, 545-587.

[2] Hannust, T., and Kikas, E., 2007, Children's knowledge of astronomy and its change in the course of learning, *Early Childhood Research Quarterly*, 22, 89-104.

[3] Nobes, G., Martin, A.E., and Panagiotaki, G., 2005, The development of scientific knowledge of the Earth, *British Journal of Developmental Psychology*, 23, 1, 47-64.

[4] Straatemeier, M., van der Maas, H.L.J., and Jansen, B.R.J., 2008, Children's knowledge of the earth: new methodoligical and statistical appraoch., *Journal of Experimental Child Psychology*, 100, 276-296.

[5] Vosniadou, S., and Brewer, W.F., 1994, Mental Models of the Day/Night Cycle, *Cognitive Science*, 18, 1, 123-183.

[6] Frede, V., 2006, Pre-service elementary teacher's conceptions about astronomy, *Advances in Space Research*, 38, 2237-2246.

[7] Arvanitis, T.N., Petrou, A., Knight, J.F., Savas, S., Sotiriou, S., Gargalakos, M., and Gialouri, E., 2007, Human factors and qualitative pedagogical evaluation of a mobile augmented reality system for science education used by learners with physical disabilitie, *Personal and Ubiquitous Computing*, 13, 3, 243–250.

[8] Billinghurst, M., 2002, Augmented reality in education, *New Horizons for Learning*.

[9] Chen, Y.-C., 2006, A study of comparing the use of augmented reality and physical models in the chemistry education. In *Proceedings of the VRCIA '06 ACM international conference on Virtual reality continuum and its applications* (Hong Kong, 2006), 369 - 372.

[10] Kaufmann, H., and Schmalstieg, D., 2002, Mathematics and geometry education with collaborative augmented reality. In *Proceedings of the ACM SIGGRAPH Conference Abstracts and Application* (New York, NY, 2002), 37- 41.

[11] Di Serio, Á., Ibáñez, M.B., and Kloos, C.D., 2013, Impact of an augmented reality system on students' motivation for a visual art course, *Computers & Education*, 68, 586-596.

[12] Frey, J., Gervais, R., Fleck, S., Lotte, F., and Hachet, M., 2014, Teegi: Tangible EEG Interface. In *Proceedings of the 27TH ACM User Interface Software and Technology Symposium, UIST 2014,* (Honolulu, Hawaï, 2014), 301-308.

[13] Wu, H.-K., Lee, S.W.-Y., Chang, H.-Y., and Liang, J.-C., 2013, Current status, opportunities and challenges of augmented reality in education, *Computers & Education*, 62, 41-49.

[14] Johnson, L., Adams, S., Cummins, M., Estrada, V., Freeman, A., and Ludgate, H., 2013, *The NMC horizon report: 2013* higher education edition.

[15] Lee, K., 2012, Augmented Reality in Education and Training, *Tech Trends*, 56, 2, 13-21.

[16] Dunleavy, M., 2014, Design Principles for Augmented Reality Learning, *Tech Trends*, 58, 1, 28-34.

[17] Cuendet, S., Bonnard, Q., Do-Lenh, S., and Dillenbourg, P., 2013, Designing augmented reality for the classroom, *Computers & Education*, 68, 0, 557-569.

[18] Chen, C.-M., and Tsai, Y.-N., 2012, Interactive augmented reality system for enhancing library instruction in elementary schools, *Computers & Education*, 59, 638-652.

[19] Kerawalla, L., Luckin, R., Seljeflot, S., and Woolard, A., 2006, "Making it real": Exploring the potential of Augmented Reality for teaching primary school science, *Virtual Reality*, 10, 3-4, 163-174.

[20] Luckin, R., and Fraser, D.S., 2011, Limitless or pointless?: An Evaluation of Augmented Reality in the School and Home., *International Journal of Technology Enhanced Learning*, 3, 5, 510-524.

[21] Zhang, J., Sung, Y.-T., Hou, H.-T., and Chang, K.-E., 2014, The Development and Evaluation of an Augmented Reality-Based Armillary Sphere for Astronomical Observation Instruction, *Computers & Education,* 73, 178-188.

[22] Pasachoff, J., and Percy, J., 2005, *Teaching and learning astronomy: effective strategies for educators worldwide*, Cambridge University Press.

[23] Hegarty, M., Montello, D.R., Richardson, A.E., Ishikawa, T., and Lovelace, K., 2006, Spatial abilities at different scales: Individual differences in aptitude-test performance and spatial-layout learning, *Intelligence*, 34, 2, 151-176.

[24] Spencer, C., Blades, M., and Morsley, K., 1989, *The child in the physical environment: The development of spatial knowledge and cognition*, Wiley Chichester.

[25] Piaget, J., and Inhelder, B., 1956, *The child's conception of space*, Routledge and Kegan Paul.

[26] Piaget, J., Inhelder, B., Lunzer, E.A., and Szeminska, A., 1960, *The Child's Conception of Geometry*, Routledge & Kegan Paul.

[27] Shelton, B.E., and Hedley, N.R., 2004, Exploring a cognitive basis for learning spatial relationships with augmented reality, *Technology, Instruction, Cognition and Learning*, 1, 4, 323-357.

[28] Vosniadou, S., Skopeliti, I., and Ikospentaki, K., 2005, Reconsidering the role of artifacts in reasoning: Children's understanding of the globe as a model of the Earth, *Learning and Instruction*, 15, 333-351.

[29] Vosniadou, S., Ioannides, C., Dimitrakopoulou, A., and Papademetriou, E., 2001, Designing learning environments to promote conceptual change in science, *Learning and Instruction*, 11, 381-419.

[30] Grandy, R., and Duschl, R.A., 2007, Reconsidering the Character and Role of Inquiry in School Science: Analysis of a Conference, *Sci & Educ*, 16, 2, 141-166.

[31] Minner, D.D., Levy, A.J., and Century, J., 2010, Inquiry-based science instruction—what is it and does it matter? Results from a research synthesis years 1984 to 2002, *Journal of Research in Science Teaching*, 47, 4, 474-496.

[32] European Commission, 2009, *Europeans, Science and Technology*, 2009.

[33] Robine, F., 2009, Réformer l'éducation scientifique : une prise de conscience mondiale, *Revue internationale d'éducation de Sèvres ,* 51, 1-9.

[34] Forsthuber, B., Motiejunaite, A., and de Almeida Coutinho, A.S., 2011, *Science Education in Europe: National Policies*, Practices and Research, ERIC.

[35] Psycharis, S., Botsari, E., Mantas, P., and Loukeris, D., 2014, The impact of the computational inquiry based experiment on metacognitive experiences, modelling indicators and learning performance, *Computers & Education*, 72, 0, 90-99.

[36] Yip, J., Ahn, J., Clegg, T., Bonsignore, E., Pauw, D., and Gubbels, M., 2014, "It helped me do my science.": a case of designing social media technologies for children in science learning. In *Proceedings of the 2014 conference on Interaction design and children,* (Aarhus, Denmark, 2014), 155-164.

[37] Slotta, J.D., and Linn, M.C., 2009, *WISE science: Web-based inquiry in the classroom*, Teachers College Press.

[38] Sandholtz, J., and Reilly, B., 2004, Teachers, not technicians: Rethinking technical expectations for teachers, *The Teachers College Record*, 106, 3, 487-512.

[39] Hew, K., and Brush, T., 2007, Integrating technology into K-12 teaching and learning: current knowledge gaps and recommendations for future research, *Educational Technology Research and Development*, 55, 3, 223-252.

[40] Fleck, S., and Simon, G., 2013, An Augmented Reality Environment for Astronomy Learning in Elementary Grades: An Exploratory Study. In *Proceedings of the 25th IEME conference francophone on l'Interaction Homme-Machine,* (Talence, France, 2013), 14-22.

[41] van Meeuwen, L.W., Jarodzka, H., Brand-Gruwel, S., Kirschner, P.A., de Bock, J.J., and van Merriënboer, J.J., 2014, Identification of effective visual problem solving strategies in a complex visual domain, *Learning and Instruction*, 32, 10-21.