A Distributed Cognition Approach to Overcome Alternative Conceptions about Light and Color

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ABSTRACT
*The purpose of the study was to report on the effects of learning with ODRES™ (**O**bserve, **D**iscuss, and **R**eason with **E**vidence in **S**cience), a computer tool that was used with elementary school children. Succinctly, dyads of sixth-grade students were engaged in distributed collaborative inquiry regarding the scientific concepts of light and color in order to solve a mystery problem about a stolen diamond. ODRES™ was employed to scaffold students' collaborative inquiry with different tools, such as the simulator that simulates the effects of the color of a light source on an object, the magnifying glass that enables students to make careful observations, and the notebook that organizes the results of students' investigations. The results showed that learning with ODRES™ positively affected students' understandings and promoted a lasting effect on their conceptions. Moreover, the results provide useful guidance about how ODRES™ can be used as alearning tool in collaborative inquiry and explain the role of discussion and investigation of inquiry processes at the level of a distributed cognitive system. Implications for designing distributed educational systems for children are finally discussed.*

KEYWORDS: *Distributed cognition, Collaborative inquiry, Computer-assisted learning, Conceptual change*

INTRODUCTION
In view of the fact that alternative conceptions can have a detrimental effect on student learning, researchers have invested intensive efforts during the last 30 years in identifying students' alternative conceptions in nearly every domain of science (Eaton, Anderson, & Smith, 1984; Kikas, 2004). Consequently, they attempted to design, develop, and implement teaching methods to break down alternative conceptions and facilitate learners' conceptual understanding and growth (Osborne, Driver, & Simon, 1996). While the impact of studies relating to learners' conceptions on educational research and practice is impressive, conceptual change in science remains a perennial problem. Many alternative conceptions continue to appear in students and adults, even after receiving instruction focusing on dislodging them (Clement, 1987). Since many science conceptions are deep seated and resistant to change, they interfere with subsequent learning, and, therefore, further research efforts in this area would be quite useful and important. In this paper, the study of alternative conceptions in science is grounded in the theoretical notions of distributed cognition. This framework situates the study of learners' conceptions in the social matrix of a learning environment, where students are engaged in shared

cognition activities mediated by technological tools, artifacts, and others (Hutchins, 1995; Salomon, 1993). Using the framework of distributed cognition, and its focus on the propagation of information, coordination of activities, and negotiation of meaning among different individuals and artifacts/tools, it becomes possible to reconsider methodological issues related to research concerning alternative conceptions, and move the study of learners' conceptions beyond the individual cognitive level (i.e., descriptive ideas located in the individual mind before, during, and after instruction) to the systems level taking into consideration social aspects of cognition. Specifically, the research questions that this study sought to answer were: (a) How does conceptual change emerge in a distributed learning environment; (b) What are the variables that may hinder a distributed cognitive system to function optimally?

DISTRIBUTED COGNITION

A main tenet of distributed cognition is that cognition is distributed across the individual, other persons, and tools. Distributed cognition theorists view cognition not as an exclusive property of individuals, but as distributed or "stretched over" an extended cognitive system, which may include the individual, other people, artifacts, and tools (Pea, 1993; Hutchins, 1995; Salomon, 1993). The distribution of cognition across people and cognitive tools and the propagation of knowledge and collaboration that occur within the extended cognitive system act as scaffolds within an individual's zone of proximal development enabling the individual to accomplish tasks that are beyond his or her own capabilities when working alone.

The implications of distributed cognition for the design of learning environments to overcome learners' conceptions in science are significant, as the framework provides a methodological approach to re-examine, and rethink conceptual change in science. From this perspective, conceptual change can most certainly be initiated and mediated by social and cultural processes. For this reason, research on conceptual change must move ahead to also examine the role of situational and cultural variables, such as, the learning task, the social interactions, and the tools and artifacts as critical components of the learning environment. This perspective does not exclude the cognitive processes of the individual mind, because the framework of distributed cognition allows not only a consideration of the role of contextual variables and group processes, but also the examination of the mental processes of the individual mind not in isolation, but in relation to other variables in the learning situation.

THE DESIGN OF ODRES™

When learners first launch ODRES™, they type in their names, so that the software can provide a personalized learning session and also keep track of user information in log files. After that, a motivating problem-solving scenario about a stolen diamond is presented to them, and they are asked to assume the role of a detective to solve the mystery. The software scaffolds students' problem-solving processes by providing them with a number of tools in order to conduct investigations and solve the mystery. For example, students can use the simulator to simulate the effects of the color of a light source on each guest's shirt. The simulator is an important tool as it tests students' hypotheses and provides immediate feedback in the form of a visual representation demonstrating that the color of a light source illuminating a colored object may modify the color of the object in specific and consistent ways. The result of each investigation is automatically recorded in a matrix. Students can use the matrix as an external memory device to organize their observations in a cohesive manner, extract patterns from the data, and propose a well-informed solution to the mystery. Students can also use the magnifying glass to carefully look for details that they may have failed to consider previously, and that might be important to consider.

METHODOLOGY

Participants

Eighteen 11-year-old students from an intact sixth-grade elementary school classroom participated in the research study. Of the eighteen participants, 11 were females and seven were males. According to the classroom teacher, the academic performance of four students was rated high, the academic performance of ten students was rated medium, and the academic performance of the remaining four was rated low to very low. Students were randomly divided into nine dyads – three dyads were of homogeneous ability and six of heterogeneous ability. Two of the three homogeneous dyads (dyads 4 and 6) were of medium ability and the other (dyad 5) of low ability. The composition of the heterogeneous dyads varied across the three achievement levels. Most students had previous but limited experience with computers, either in their school computer lab or in their homes, while some of them had no experience whatsoever.

Research Instruments

Two researcher-made tests were used to assess students' ideas about the relationship between light and color. One test was used both as a pre-test and post-test, and another as a retention test. The pre-test was administered three days before the actual study took place and the same test was administered again as a post-test after the completion of the study, that is, three days after the pre-test was administered. Each administration lasted approximately 20 minutes. In the pre-test and post-test, students were presented with a picture depicting a room lit with white light (sunlight) and in which seven items were shown. The seven items were: (a) a blue couch, (b) a white armchair, (c) a red cabinet, (d) a black flower-pot, (e) a green plant inside the black flower-pot, (f) white-colored walls, and (g) a white-colored floor. Then, students were told to assume that the same room was lit with a different light color and were asked to decide whether the color of the objects would be different. They were also given colored pencils to appropriately color the objects in the picture, and in addition, to explain and justify their thinking. Students received one point for each item in the picture that they correctly colored provided that they also wrote a correct justification for each answer. Thus, scores on the pre-test ranged from 0 to 7. At the end of the study, the three versions of the same test were administered as post-tests, but it was made certain that no student received the same version of the pre-test as a post-test. The retention test was administered three months after the post-test. Students were given again the picture of a room, lit with white light (sunlight), which had (a) white-colored walls, (b) a white-colored floor, (c) a black box, (d) a white box, (e) a red box, (f) a green shelf hanging on the wall, and (g) a blue cabinet. Then, the students were told to assume that the same room was lit with a different light color (i.e., blue, green, and red), and were given colored pencils to appropriately color the objects in the picture. In addition, students were also asked to write down reasons for their decisions. The retention test was administered in 20 minutes and the same range of scores (0 to 7) was used. In the three testing conditions, students worked individually (not in dyads).

Research Procedures

The study took place in an intact sixth-grade elementary school classroom during a science lesson. In the classroom, there were no computers and nine laptop computers were brought in, one for each dyad. The dyads were seated in a ¶ configuration, and no two dyads adjacent to each other worked with the same version of the software. Students in their dyads first worked with the software for 60 minutes. Then, they were asked to participate in a classroom discussion that lasted 20 minutes and was facilitated by the first author of this paper. During the discussion, the facilitator asked students to name the thief and to justify their conclusion. The facilitator listened to students' proposed solutions and asked them to work with the software for 25 more minutes in order to look for new evidence confirming or disconfirming their claims. Then, the facilitator engaged students in a second discussion that lasted 15 minutes. In the second discussion, students presented their new solutions or supported their initial solution with new evidence. Thus, during the two discussion sessions, the facilitator only listened to what students had to say and, in the first discussion, encouraged them to look for more evidence in order to back up their claims.

Data Collection Methods and Analyses

A mixed method approach was used to collect both qualitative and quantitative data. Qualitative data were collected to document the discourse of the students in each dyad interacting with each other and with the computer tool. Qualitative data also included information from video cameras and observation/field notes from two other researcher-participants. For videotaping purposes, ten cameras were used - one camera for each dyad, and another for capturing the classroom interactions. Also, data related to students' interactions with ODRES™, such as, for example, learners' hypotheses and explanations were automatically saved by the software in log files. Additionally, quantitative data related to students' performance were collected with the pre-test, post-test, and retention test. All videotaped sessions were transcribed and then analyzed from a systems perspective (Ackoff & Emery, 1972). The unit of analysis was a distributed cognitive system composed of the two individuals in each dyad interacting with each other and with ODRES™. The main focus of the analyses was to analyze the interactions in the distributed cognitive system, to identify how and why a joint cognitive system as a whole performed, and to identify variables that might have hindered the joint cognitive system to function optimally.

RESULTS

Students' performance on the pre-test, post-test, and retention test

The mean on the pre-test was 4.11 and the standard deviation was .83. The mean on the post-test was 5.17 and the standard deviation was 1.29. A *t*-test for paired samples was conducted and it was found that the difference between participants' performance on the pre-test and the post-test was statistically significant, $t = -4.24$, $p < .01$. Three months after the post-test was administered, students were given the retention test to complete. The mean was 5.17 and the standard deviation was 1.29. A t-test for paired samples was performed, and it was found that the difference between participants′ performance on the pre-test and the retention test was statistically significant, $t = -4.24$, $p < .01$.

A qualitative analysis of the reasons students gave in support of their answers revealed a hierarchy of different groupings, showing that the students constructed different alternative ideas about the effects of the color of a light source on the color of objects. Specifically, there was a group of students who did not express consistent ideas or did not follow the instructions on the tests (Category F). Some other students suggested that the color of objects always takes the color of the light source (Category E). For example, if a room is lit with red light, then all objects in that room will become red. Light was considered as having material existence and "could cover all the things in the room." Other students, forming three different subgroups, had the idea that the color of a light source affects the color of objects in various ways. Some insisted that only objects with white color always take the color of the light source, but the other objects keep their initial color (Category D). In reality, these students did not consider "white" to be a color. Other students proposed that white-colored objects take the color of the light source, while those objects having the same color as the light source keep their color, and objects with different color (including the black color) take a color that is a combination of their initial color and the color of the light source (Category C). Another group of students had similar ideas, but insisted that objects with black color remain unaffected without recognizing, of course, that such an outcome was related to the property of "black color" to absorb all frequencies of white color (Category B).

Students' interactions between them and with ODRES™

The analysis focused on five different aspects of the whole process, namely: (a) getting familiar with the interface of the tool, (b) using prior knowledge to solve the problem, (c) recognizing and managing cognitive conflict, (d) hasty and unjustified conclusions, and (e) reaching an evidence-based explanation.

Getting familiar with the interface of the tool

At the beginning, students in each dyad spent considerable time trying to understand how to use ODRES™. Students' discourse revealed that they were not very familiar with computers and, consequently, they struggled with the interface of the system. For example, students S1 and S4 (dyad 1) felt unsure about which buttons to click on and persisted in asking the researchers for assistance.

> **S1:** Sir, do we need to click here? **Researcher:** (No answer. He pretends that he is busy.) **S4:** Click here. **S1:** No. **S1:** Sir, do we need to click here? **Researcher:** Yes. **S1:** Sir, what should we choose here? **Researcher:** Please concentrate and you will figure things out.**S1:** Should we click here? **Researcher:** [no reply] **S4:** No, not here. **S1:** Sir, we clicked here and it did not continue. **S4:** Click again.**S1:** Hmm, now it did it.

Using prior knowledge to solve the problem

The results indicated that students initially relied on their prior knowledge in order to solve the problem. For example, students S1 and S4 (dyad 1) used their knowledge about mixing paints of different color to form initial hypotheses about the effects of the color of a light source when illuminating a colored object.

> **S1:** We have dropped the guy with the blue shirt in the red room. What would the color of his shirt be? **S4:** That would give us purple. I will show you. **S4:** Sir, can I have colored pencils? **Researcher:** Yes, sure. Why do you need them? **S4:** I want to color something. *[S1 and S4 use a blue color pencil to color a white piece of paper and then on top they colored it again with the red pencil.]* **Researcher:** What do you think it will happen? **S4:** The new color will be purple. **Researcher:** So, is this your hypothesis? **S1 and S4:** Yes!! **Researcher:** Ok, now you can check with the simulator and find out whether you are correct.

These dialogues stress the implications of prior knowledge on any subsequent learning, because existing conceptions act as intuitive screens through which any new experience is explained, and provide direct support to constructivist approaches of teaching and learning. Evidently, these students insisted that the rules for mixing paints and crayons applied also in the case of mixing the color of a light source with the color of an object.

Recognizing and managing cognitive conflict

After forming initial hypotheses, students used the simulator to check their validity. In those cases where the simulated outcomes confirmed students' initial ideas, they simply carried on with their investigations. In those cases where the simulated outcomes provided evidence contradicting students' hypotheses, students either changed their initial ideas without raising questions or expressing disbelief (students S8 and S11), or they insisted on keeping their first ideas and ignored the outcomes of the simulator (students S16 and S17), which provided contradictory evidence.

> **S8:** What will the color of Mr. Blue's shirt be in the blue room? **S11:** Let's read the directions again. [*They are reading the directions*] **S8:** The color will be black. **S11:** No, the color will be blue. Definitely blue. **S8:** No white. **S11:** Let's check. [*They observe that it is blue*] **S8:** Ok, it is blue, let's write it. **S11:** Let's drop Mr. Blue in the red room. **S8**: It will be purple. **S11:** No, blue. No, purple. Ok let's check. **S8:** Oh, it is black. **S11:** Ok, let's write black.

The previous dialogue clearly indicates a passive acceptance of the outcomes of the simulator without recognizing or paying attention to the evidence that was contrary to their expectations. It was thus unclear whether the contradictory evidence created any cognitive conflict in the individual minds of the students. Consequently, ODRES™ did not function as it was expected and did not help these students to go through the process of managing cognitive conflict that is considered as a prerequisite for conceptual change.

Hasty and unjustified conclusions

Students were very enthusiastic about the problem they had to solve, and all dyads except one (dyad 5) were very eager to announce to the researchers the thief of the diamond even before carrying out a single investigation with the simulator. The researcher, as shown in the excerpt below, had to explicitly tell the students that they had to systematically collect evidence, and based on the evidence to decide who stole the diamond.

> **S5:** Sir, we know who stole the diamond. **Researcher:** Who do you think? **S5:** Mr. White. **Researcher:** Can you explain why? **S6:** Do you also want a reason? **Researcher:** Of course, how can you be sure that it is Mr. White? **S6:** We are not sure. **Researcher:** Have you collected evidence indicating that Mr. White stole the diamond? **S6:** No. **Researcher:** How do you know then? **S5:** It is what we think. **Researcher:** That is not enough. You need to collect evidence. **S5:** OK.

In the excerpt above, both students in the dyad expressed the idea that only white objects change color when being illuminated by colored light, because, from their own perspective, white was not a color. This dialogue provides evidence indicating that there were students in the classroom who were rushing to hasty and unjustified conclusions and seemed unable to suspend their judgement until they could find evidence to support their conclusions. According to the classroom teacher, students perceived learning with ODRES™ as a game and they were all rushing to find the solution to win.

Evidence-based explanations

Those students who were able to solve the problem formed explanations based on the evidence they collected. Their statements indicated that they were able to comprehend that color is not an exclusive property of an object, and that when a source of light illuminates a colored object, the color of the light source does not mix with that of the object. However, as the excerpt below shows, students' arguments were based on their sensory experiences or the observable changes of the color of objects. As it was expected, they could not relate the outcome to the nature of white light, the properties of matter, and the mechanism of vision, and it was not expected from them to comprehend that the color of an object relates to the properties of matter to absorb some frequencies (colors) of the compound white light and reflect others that reach the eye and so decide the color of the object.

> **Researcher:** So, who do you think stole the diamond? **S10:** Definitely Mr. White stole it. **Researcher:** Are you sure? **S10:** Yes, we have evidence to prove it. **Researcher:** Can you explain it? **S10:** Yes, when somebody wears a white shirt, and enters a room, the color of the shirt takes the color of the

room. So, the white in the blue will become blue, in the red will become red, and in the green room will become green. So, it must Mr.White. **Researcher:** OK, but what if the color of Mr. White's shirt was blue? **S10:** The blue in blue will remain blue, and in all other rooms black. **Researcher:** But, previously you said that the blue shirt in the red room will become red. **S10:** Yes, but I was wrong.

DISCUSSION

In this study, we first explained the design of ODRES™, a computer tool that was used with elementary school children in science, and we then discussed the effects of learning with ODRES™ on students' conceptions about light and color. The results showed that there was a significant and lasting change on students' understandings about light and color. Specifically, the results showed significant differences between the pre-test and the post-test, and between the pre-test and the retention test, but there were no significant differences between the post-test and the retention test. Nonetheless, more detailed examination of the results indicated that change in conceptual understanding was restricted only to eight students and that only the students in two dyads, dyad 2 and dyad 7, worked well together. Thus, it seems that the other students who showed evidence of conceptual change were, in reality, working alone since their partners showed no evidence of conceptual change and/or understanding. Based on the results, it seems that better learning outcomes could have obtained if the dyads/groups were formed in a way so that all students in a group were required to equally contribute to the collaboration. The results indicate that the dyads were not functioning effectively, since, for the most part, only one of the two students in each dyad was actively engaged in the learning activity, whereas the other student seemed to be a passive observer. Most importantly, these findings shed light on the nature of distributed collaborative inquiry and identified factors that may impede conceptual change in a distributed computer-enhanced learning environment. Based on the qualitative results of the study, it becomes evident that effective distributed collaborative inquiry can take place only when the tools supporting the inquiry afford working spaces that allow learners to communicate, share points of view, and organize collaborative work. Such working spaces should allow all individual cognitions to be equally represented so they can be distributed across the extended cognitive system for consideration and evaluation. Failure of educational software systems to host collaborative working spaces can result, as the findings of this study showed, in distributing ideas, coming most probably from the most assertive students in a group, which might not always be correct. What's more, allowing for all cognitions to be individually represented in the distributed cognitive system enables the systematic examination of the contribution of each participant in the extended cognitive system.

Furthermore, according to the results, the cognitive processes underlying the collaboration and learning of young children in a distributed inquiry environment are not the same as the cognitive processes, reported in the literature of distributed cognition, of highly skilled experts, such as pilots and air-traffic controllers (Hutchins, 1995) who are usually the users of distributed systems. As the results showed, not only young learners have persisting misconceptions, but they also fail to recognize and manage cognitive conflict when it is presented to them. Therefore, the design of educational software for young children should afford scaffolds for helping them to recognize and manage cognitive conflict. Scaffolds for recognizing and managing cognitive conflict can take the form of question and reflection prompts every time a discrepant event is presented to the learners. Finally, as the findings showed, students were excited to work with ODRES™ because of its attractive multimedia features. For many students, ODRES™ was an interesting and playful activity, but not an activity related to learning about light and color. Thus, a third issue that needs to be considered in the design of educational software systems for children is learners' perceptions of the task and how often they need to be taken into consideration. Our judgment at this point is that they should always be considered, because as our data strongly suggest learners' perceptions of the task heavily operate in the learning task as they easily get distributed and are just as viable as other more concept-related cognitions.

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