The Journal of Interactive Online Learning *Volume 2, Number 2, Fall 2003*
www.ncolr.org *ISSN: 1541-4914*

The Role of Online, Asynchronous Interaction in Development of Light and Color Concepts

Kevin Carr
George Fox University

Francis Gardner
Columbus State University

Michael Odell
University of Idaho

Ted Munsch
Alaska Pacific University

Brent Wilson
George Fox University

Abstract

*This study investigates the effect of asynchronous, online interaction on student conceptual understanding of light and color. Two versions (N and Y) of an online independent study module on light and color were randomly assigned to students (*N = *144) enrolled in introductory science courses for non-science majors at three higher education institutions. Version Y included Internet message boards to facilitate required peer-peer interaction about the module content. Version N lacked message boards. The Light and Color Concepts Assessment Instrument (LCCAI) was administered to subjects in a pre-post test experimental design. A multivariate analysis of variance was calculated, showing that student achievement on two of the four LCCAI test items varied significantly as a function of the module version studied. Analysis of over 500 online postings in light of social constructivism indicated that significant scaffolding took place during online interactions. The authors conclude that the availability of interaction likely played an important role in online learning.*

In fall 2001 the authors developed an online independent study module entitled Mission to Mars. (The module may be browsed at http://209.170.250.48/NOVA/) The module was designed to help beginning physics students develop understanding of "remote sensing," the use of incoming light from space to gather information about remote objects and places. Remote sensing technology utilizes many elementary principles of light and color. Mission to Mars is designed to support development of several key concepts of light and color that provide the foundation for remote sensing (see Table 1).

Table 1

Learning Objectives for the Mission to Mars Online Module

- Students will demonstrate understanding of the additive and subtractive primary colors,
- Students will demonstrate understanding of the mechanism of human vision as a detector and analyzer of light,
- Students will demonstrate understanding of line spectra,
- Students will demonstrate understanding of light spectra and its role in the remote sensing of astrophysical phenomena.

Mission to Mars is delivered in an online, student-directed format using an Internet Web browser. Mission to Mars contains student-controlled simulations, open-ended questions, and immediate feedback designed to encourage students to reconsider their current conception of light and color, and to apply their new ideas to understanding current space science research. Mission to Mars also features online message boards to facilitate student interaction.

Mission to Mars was completed by 144 undergraduate non-science majors at three higher education institutions from spring 2001 to spring 2003. This study investigates the role of online interaction as part of the Mission to Mars learning module in student conceptual development. The authors conclude that message boards can play a positive role in aiding student conceptual change with regard to light and color concepts. Message boards are most effective if implemented within a constructivist pedagogic framework that encourages scaffolded interaction.

Review of Research

Research suggests that student misunderstanding of light and color concepts is deeply engrained and resistant to traditional, expository instruction (Wanderslee, Mintzes, & Novak, 1994). Successful learning of scientific concepts is facilitated by activities that confront student misconceptions through direct experience and simultaneous feedback (Penner, 2001). The process of exploring a phenomenon, reconsidering discrepant observations, and reapplying new concepts to new phenomena, widely known as the “learning cycle,” evolved from the cognitive constructivism of Jean Piaget and has been adapted by many authors as a model for instructional design in science (Tobin, Tippins, & Gallard, 1994). Although originally espoused as a means of increasing learning opportunities and retention of material learned by precollege students, recent authors conclude that the “constructivist” approach to teaching and learning can be successfully implemented with positive results in college science classrooms (Bennett &

Green, 2001; Bostock, 1998; Hendry, Frommer & Walker, 1999; Lawson & Johnson, 2002; Stage, Muller, Kinzie, & Simmons, 1998; Sutherland, 1999).

Scaffolding and Conceptual Change

In addition to direct experience and feedback, recent research also suggests that social interaction plays an important role in reforming student understanding of science concepts (Hodson & Hodson, 1999). One way of conceptualizing interaction is through the metaphor of "scaffolding." The scaffolding metaphor, associated with the social constructivist theorist Lev Vygotsky, emphasizes the role of experts and more advanced peers in facilitating the development of new concepts in a learner (Berk & Winsler, 1995. Conceptual development occurs in group social interaction through the sharing of language among group members of differing understanding (Vygotsky, 1978). Scaffolded interaction is characterized by participants restating, rewording, and building on the ideas of others (Berk & Wisnler, 1994).

Online Interaction

In online courses, social interaction is limited by the technology provided, by student accessibility, and by student comfort in using the provided tools. Some researchers argue that in the midst of the proliferation of online instruction, constructivism must replace instructivism as the means for providing educative learning opportunities, especially in science. (Jonassen, Davidson, Collins, Campbell, & Hang, 1995; Rowntree, 2003) It is therefore vital that we understand the nature of social interaction in the online medium, and how common online communication tools facilitate learning in a constructivist online instructional design.

The role of social interaction in online learning has been the subject of extensive recent research with the advent of Internet technology (see Table 2). Much of the research reviewed for this study involved the use of online interaction to foster and support learning, but many of the conclusions focused on affective outcomes such as student satisfaction and student learning styles. Some studies compared online interaction to traditional, face-to-face interaction. No study reviewed attempted to compare peer-interactive online instruction to similar online instruction without peer interaction.

Table 2

Examples of Research on Online Interaction

Research Outcome	References
Discussion board interaction enhances student satisfaction with online instruction	De Simone, Yiping, Dehler, & Schmid (2000).
Student satisfaction with message boards is related to learning style	Becker & Dwyer (1998), Blum (1999)
Message boards are an effective means of support in online environments	Bodzin & Park (1998), Harasim (1993), Hegngi (1998)

Focus of Inquiry

This study investigates how the presence of online interaction as part of the Mission to Mars learning module affected student understanding of light and color concepts. The hypothesis that online interaction is a positive factor in conceptual development is tested. The textual content of student interactions is analyzed to better understand how online interaction functions to foster conceptual change through scaffolded interaction.

Methods

Two versions (N and Y) of Mission to Mars were constructed. Version Y included a set of embedded online message boards through which subjects were required to interact with each other about module items. Version N lacked message boards. Achievement of learning objectives was measured in a pre-post test design using the Light and Color Concept Assessment Inventory (LCCAI). Differences in achievement between groups were evaluated for significance (a = .10) by calculating a repeated measures multivariate analysis of variance (MANOVA).

To add depth of meaning to the above quantitative analysis, message board content was analyzed. The analysis of message board text follows the pattern of action research as defined by Arhar, Holly, & Kasten (2001) in that it is (a) conducted mainly by insiders and participants rather than by outside observers, and (b) includes self-critical inquiry, with interpretations and judgments made by the participants themselves. The intent of including message board content in this study is to use the voices and experiences of the participants to help understand the role online collaboration played or did not play in learning. Message board content was parsed, categorized, and interpreted using the researcher-as-instrument paradigm suggested by Wolcott (1994).

Subjects

The subjects of this study were comprised of 144 undergraduate students enrolled in introductory science courses at three regional universities. Eighty-five students, representing a variety of non-science majors, were drawn from a liberal arts physics course (Physics of Everyday Life) at a small liberal arts university (G) in the Pacific Northwest. Also representing a variety of non-science majors were 36 students drawn from an introductory physical science course at a mid-sized Southern university (C). The remaining 23 subjects were enrolled in an integrated science course for preservice elementary teachers at a major research university (I) in the Rocky Mountain region.

Subjects at each institution were randomly assigned to one of two groups. Groups N (n = 72) and Y (n = 72) studied versions N and Y of the online module, respectively. The LCCAI pre and post assessments were completed satisfactorily by 144 students.

Instrument

The Light and Color Concepts Assessment Instrument (LCCAI) was developed by the authors during fall 2001 (see Table 3). The LCCAI consists of four open-ended questions used to test achievement of the four module objectives. Each item was hand-scored on a scale of 0 to 5. Scoring was completed blindly by the authors with respect to grouping of subjects.

Content and construct validity was ensured by using established test banks, as well as published research papers, in the construction and selection of items (Hewitt, 1993; Hoadley & Linn, 2000). A pilot test was conducted (n = 16) with split-halve Cronbach's alpha, Pearson product moment split-halve, and inter-item correlation measures of reliability calculated (a = .87, r = .90) (Black, 1999). Both internal analyses of the pilot LCCAI indicate a sufficient degree of instrument reliability.

Table 3

LCCAI Test Items

Light and Color Concept	Pretest Item	Posttest Item
Color mixing	Imagine a leaf that looks green in sunlight. What color would it appear if illuminated by red light? By cyan light? Explain.	Imagine a piece of cloth that looks yellow in sunlight. What color would it appear if it were illuminated by green light? By blue light?
Eye as a detector and analyzer of light.	If you stare continuously for 2 minutes at a bright blue object, and then shift your gaze to a white background, you will see a yellowish after-image. What causes the after-image? Explain.	If you stare continuously for 2 minutes at a bright red object, and then shift your gaze to a white background, you will see a blue-green after-image. What causes the after-image?
Line spectra.	In a dress shop with only fluorescent lighting, a customer insists on taking dresses into the daylight at the doorway to check their color. Is she being reasonable? Explain.	I recently decided to paint my living room. I went to the hardware store, which has fluorescent lighting, and picked out some paint samples. When I got them home that night, they looked more greenish than I remembered them looking at the store. In the morning I looked at them again and the colors looked slightly different again. Explain.
Remote sensing.	We can see, using telescopes, interstellar gas formations thousands of light-years from earth. We believe that some of these formations are expanding clouds of mostly hydrogen gas. In other words, we know both the movement and composition of the clouds. Explain how we know these things about the gas formations when we can barely see them in telescopes.	We have no actual samples of material from stars, and most stars' movements are not visible to the naked eye or in telescopes. Yet, we believe we know the chemical composition of the stars, as well as their slight movements relative to the earth. Explain how we know these things when we can only see tiny points of light in telescopes.

Research Hypotheses

The hypothesis $H_0: \mu_N - \mu_Y = 0$ was tested using a repeated measures analysis of covariance (ANCOVA) in a pre-post test experimental design (a = .10). A repeated measures multivariate analysis of covariance (MANCOVA) was also calculated to test individual hypotheses $H_0: \mu_{Ni} - \mu_{Yi} = 0$, i = (1, 2, 3, 4) where i represents each LCCAI test item.

Results

Calculation of a repeated measures *t* test showed that versions N and Y of the Mission to Mars online module were both effective in promoting learning of concepts of light and color ($t = 12.97$, $p < .001$, see Table 4).

Table 4

Repeated-Measures t Test of Student Performance on the LCCAI

	M	*SD*	*n*	*df*	*t*
Pretest (PRE)	8.1	3.2	144		
Posttest (POST)	12.1	4.28	144		
POST-PRE	4.0	4.02	144	143	12.97*

*$p < .001$

Calculation of a repeated measures MANOVA using each LCCAI pre-post test item (Q1, Q2, Q3, Q4) as a dependent variable and institution (C, G, I) and version (N, Y) as fixed factors showed that the version studied was an insignificant factor in the full linear model of student achievement. However, analysis of the effect on each test item as an individual component of the model shows that posttest results on LCAII questions 2 and 4 varied significantly as a function of the version studied (see Table 5).

Table 5

MANOVA for LCAAI Pre-Post Test

Source	Dependent Variable	*F*
INSTITUTION	Q1	6.06**
	Q2	2.821**
	Q3	5.458*
	Q4	6.839**
VERSION	Q1	1.185
	Q2	2.990*
	Q3	0.797
	Q4	3.668*
INSTITUION X VERSION	Q1	2.777*
	Q2	6.414**
	Q3	1.912
	Q4	2.413*

*$p < .10$ **$p < .05$

Interpretation

The 72 students using module Y posted over 500 messages on the message board, an average of over 7 postings per student. Approximately 60% of the postings were in response to the work of other students. The preceding quantitative analysis suggests that the inclusion of message boards for peer interaction has a subtle, but detectable effect on student learning. In order to better understand the measured effects, the authors examined how the instructional design and message board content of the Mission to Mars module related to each of the four concepts measured by the LCCAI. In general, the authors conclude that message boards were most powerful when groups of students entered the discussion with diverse levels of conceptual understanding, resulting in scaffolded interaction for the majority of students.

Examples of Scaffolded Interaction

Scaffolded interaction is characterized by diverse levels of student understanding, and frequent restating, reformulating, and extending of peer ideas. The following are case studies of scaffolded interactions the authors found in the message board record.

Green and red make yellow? One of the first tasks posed by Mission to Mars involves using a JAVA-based simulator to experiment with mixing different colored lights on the screen. Students are first asked to predict the outcome of a light mixing experiment, in this case, the mixing of red and green light. Students are then asked to perform the experiment using the simulator, and comment on the results by posting thoughts and ideas to an online message board. The students are also asked to respond to the ideas of others. The following are illustrative case studies of message board interactions:

Nancy: I guessed that mixing green and red would make a purplish-yellow color, since green is a combination of blue and yellow and so would add those aspects to the red. I was incorrect.

Chris: I thought the mixture would produce yellow and it turns out I was right. I can see where you thought there might be purple too, a good guess, but I think you would need blue as well.

Tim: I guessed similar to Nancy, I was going from experience with acrylic paints and water color, so I thought that it would turn out kind of a brownish color. I too, was wrong.

Andy: I thought it would be brown too.

Misconceptions research has pointed out the importance of eliciting student predictions about a phenomenon (Brooks & Brooks, 1999, pp. 60-84). In Nancy's initial posting, she makes her prediction, stating that red and green light make purple, and explains it, using the common misconception that blue and yellow make green. Tim adds that perhaps his misconception arises from experience with mixing paints. Another group of students discussed the same experiment:

Cortney: I found it interesting that red and green made yellow. I did a little experiment at home using food coloring and it didn't turn out yellow but rather a brownish-purple color. My only thoughts on this would be that the brightness of the red and green make a difference in the ending color. The food coloring colors were darker and online the mixings were much brighter. Maybe those colors had more yellows to begin with, hence the ending result.

John: Maybe that the food coloring was in water had something to do with it. Water has its own composition and its own color so that might have tainted it.

Marcie: From what I have discovered/remembered light has three different primary colors than paint and they also mix differently. The three colors are red, blue, and green instead of red, blue and yellow. They mix to create yellow, cyan, and magenta which is different than what paint does so we can't base our judgements on what we have learned with paint and food coloring.

Joann: Mixing paint and mixing light is a completely different thing. Kind of like when you're in kindergarten and you color green on top of blue, it makes yellow - but with lights, those colors just make a lighter blue.

In this interaction, Cortney, an elementary education student, shares her own experience trying to make sense of the light-mixing experiment, noting that the subtractive colors of paint seem "darker" than those seen in the simulation. This observation opens the door to understanding that adding light is different than adding paint, an idea suggested by Marcie, a student with extensive background in high school physics. Joann manages to merge both concepts. This interaction is suggestive of scaffolding (Berk & Winsler, 1995. Marcie was able to take the lead in helping others make sense of their observations.

In another phase of the activity, students are asked to predict the outcome of mixing blue and yellow light. In this thread of the discussion, scaffolding involving different levels of conceptual understanding is also seen:

Joshua: I think that blue and yellow made white because yellow was already made up of green and red. Essentially, you have blue, green, and red all mixed together.

Marcie: I also realized that yellow is already red and green mixed together so when blue is added all the primary colors of light are present so white light is created. This is because white light by definition is all the colors of light combined.

Chris: I don't quite see how blue green and red all mixed together would leave you with white.

Cortney: This is an interesting thought...I never thought of it this way before. I am so used to using the mediums I was taught with in school but dealing with light is different. And earlier on the first mixture red and green did make yellow so you are taking a mixed color and adding it a color that is already there...I like that thought.

In this case, the online interaction between two students who had substantially grasped the color-mixing concept served to scaffold the learning of Chris and Cortney.

Does light have temperature? In another part of the online module, students were asked to use a diffraction grating to observe changes in the spectrum emitted by an incandescent light connected to a dimmer switch. The interaction concerns the effect on the spectrum of increasing the intensity, and thus, temperature, of the light:

Jessica: well, I couldn't find a bulb on a dimmer switch, but I would think, by my own reasoning and by hints seemingly given in the reading, that the higher the switch turns it on, the brighter the color on the spectrum and the hotter the temperature.

John: Blue seems to get more vibrant than other colors

Leila: so if the blue is more vibrant, does that mean it is stronger, cooler and emitting a LOT less? or is that color just picked up better in the diffraction?

Carla: when I made my observations I noticed the same thing. I actually ended up observing a hologen [*sic*] light that had a dimmer so I wasn't sure if the blue was because of that—apparently not.

In this exchange, Jessica, who was unable to perform the actual experiment, interacts with others who had made the correct observation that the spectrum changes when the temperature is increased. The following group extended their observations to include references to common experiences:

Carla: Television and movies give great examples of how spectra might be used to determine an object's temperature. Look at all the movies where they have 'night vision' goggles that allow the viewer to see where 'living' things are based on the heat their bodies transmit. It is interesting to get a glimmer of how this works in other areas.

Matt: Night vision goggles are the first thing I thought of when talking about temperature and color. It made me remember the movie "Predator." the only way he could see Arnold was using heat sensors, which showed different colors depending on the temperature.

Tamara: Excellent point, matt! if it happened in a movie it must be true! just kidding. I think heat is another one of the properties of light waves.

James: the predator alien could see using infrared, temperature-vision. but how come when AHNULD covered himself up with mud, the predator couldn't see him. is amazon river mud the ultimate insulator?

Robbie: This brings up a great question james. If we can be so easily deceived by something as simple as mud, is it possible that we are being deceived by other chemicals and substances in space, which are throwing off our supposed knowledge of our stars and suns chemical and temperature consistencies?

Color Mixing and Line Spectra: Missed Opportunities for Scaffolded Interaction

The positive effect of message board interaction was demonstrated for two of the four tested concepts. Color mixing and line spectra were two concepts for which the positive effect of message boards was not demonstrated. Analysis of message board content suggests that extensive scaffolding did not take place in the message board interactions related to either concept.

In the case of color mixing, most students had a low initial understanding after interaction with the module components (an interactive JAVA color mixing applet). Student postings were typified by confusion, frustration, and empathy for peers:

> S1: i was also surprised to see that the colors made green. i dont know why they do that.
>
> S2: now I am lost because I thought they would turn green, but they turned....Yellow?

Given the level of confusion for many, it is not surprising that students were unsuccessful in generating increased understanding through message board discussion.

In the case of line spectra, most students demonstrated high initial understanding after interaction with the module components (diffraction gratings and common light sources). Typical responses were typified by confidence, correct understanding, and agreement with peers:

> S3: An object absorbs different colors from the light and then project its true color in the light spectrum
>
> S4: just as light can radiate from a source it can also absorb into a source causing dark lines. This would explain a lot about darkness. hmm. there are many different things which can absorb light, one of them is gas. we can use emission and absorption to determine the chemical composition of starts because different elements absorb or repel to different degrees of color. A really bright color may be caused by one type of element.

Many students began the message board interaction with a high level of understanding of line spectra. Without much cognitive distance between students, they were unable to generate increased conceptual understanding through message board discussion. Ironically, the core reason for the lack of concept development in the message boards—lack of cognitive distance—is the same for both “confused” and “expert” groups of students. When groups were homogeneous with respect to conceptual understanding, scaffolding was reduced, attenuating the effect of message board interaction.

Remote Sensing: Building Understanding Through Scaffolded Interaction

The authors observed that the richest scaffolded interactions occurred when students discussed remote sensing as the summary activity of Mission to Mars.

Coincidently, students who engaged in online interaction using version Y of Mission to Mars demonstrated significantly greater gains on the concept of remote sensing (LCCAI Item 4) than their peers using the non-interactive version ($p < .01$). This finding suggests a positive link between the level of scaffolding in online message boards and conceptual development.

How Do We Know What the Rocks on Mars are Made of?

As the final activity of the unit, students are asked to analyze a graph showing the color spectrum reflected by a Martian rock under illumination by a NASA detector on board the Martian Rover (see Figure 1). This question is the "capstone" activity of the *Mission* to *Mars* module. Following are two examples of message board interactions:

Example 1

Pisey: From the graph I would assume that the rock would appear to be reddish color with the naked eye. The reason for my assumption is because the highest visible color of the spectrum is between red and infrared, but once it reaches infrared it would not be visible with the naked eye.

Jessica: to me, it looks as if it shows up more in the green range than it does in the red because it hits infrared before the amplitude gets very high

Tim: I think that it would probably be green, and if the red was visible at all, it would just make the green a little lighter. So, the other possibility would be a yellowish green.

Sarah: would it be more green than red when the graph elevates towards the middle of the two. I think yellowish is more accurate than green...

Marcie: I agree with you, I also thought that the color would turn out to be a redish yellowish color, I really don't think that there would be much green in the color because even though there is green in the color, the red would balance it out to create a yellowish color.

Pisey: From my point, I thought that the color would be reddish because it was increasing towards the infrared. Even though before the graph reached infrared it was higher, so the color was almost fading from red to not visible. But look from amplitude I agree that the green is more.

Carla: I see all four lines peaking in, or at the end of the red range, while their dip looks to be in the green range, so I guessed that the color of the rocks would be reddish. Of course, I have to admit that 'reddish' seems to [be] more of a rock color than 'bluish' or 'greenish'. Every time I think I get this stuff figured out, I quickly discover how wrong I am—ugh!

Sarah: that yer really so wrong after all? You did have a valid point and good reasons for your thoughts....I still think the color would be more of a middle of the road between green and red (being yellow or orangish).... but anyways remember Aristotle and Galileo and how they weren't exactly accurate but nonetheless their ideas were valid and helped the progression of science (and understanding) as a whole! =)

Josh: Maybe it's just me, but the graph seems rather odd and nonsensical.

Sarah: It demands that we think about it. That's all.

Example 2

Jennifer: doesn't it depend on what the rocks are made up of to determine the color?

Nicole: When the line on the graph is lower than the others, it is the one truer to the color.

Amanda: I think that is why it reflects certain colors...because of what it is made of.

Liesl: yes, but isn't the color reflected an indicator of what the rock is made of? The two work together.

Jimmie: yeah this sounds right, color of rock and chemical makeup are directly related.

Jeremy: The color of the rocks and the chemical composition of the rocks work hand-in-hand. You can use one to make inferences about the other and come to an overall better understanding of the materials that you are dealing with.

Heidi: They do work hand in hand, because different materials absorb different colors of light, so the spectrometer would only see the reflected color. The same way that there was black lines in the spectrum of light through helium.

The students in these examples consistently reflect on, and build from, each other's ideas. Within the thread of the text we see a range on understanding, from Jennifer, who is actively questioning her ideas, to Heidi, who articulates her more expert view using the language and ideas of others.

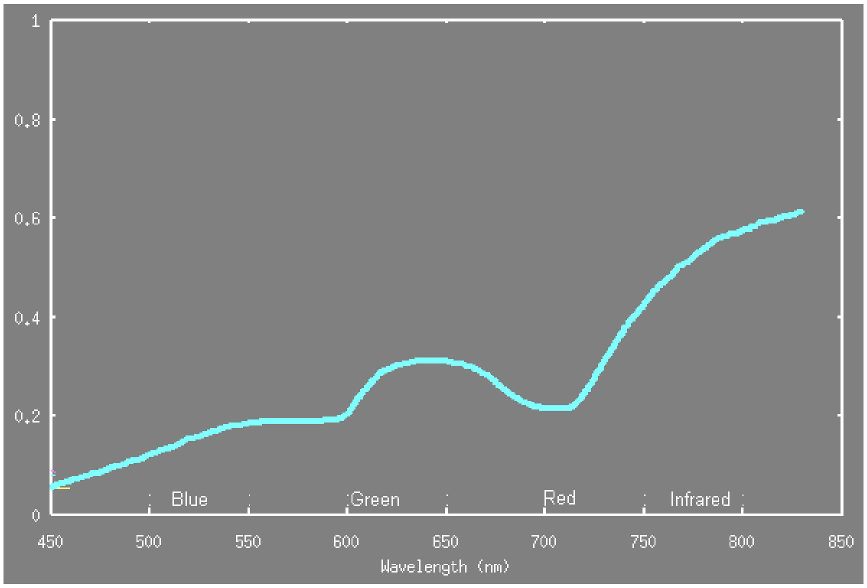

Figure 1. **Simulated spectral output of unknown Martian rock.**

Discussion

This study supports the literature on the general effectiveness of online learning modules in science instruction (Ruchti & Odell, 2001) as exemplified by the significant changes in pretest to posttest scores evidenced on the LCCAI across the institutions in the study. The study further demonstrates the effectiveness of asynchronous interaction as a part of the Mission to Mars online module. Students willingly exchanged ideas and questions regarding the module contents. On two of the LCCAI questions, understanding of concepts may be attributed to this exchange of ideas as students with previous background knowledge or more sophisticated understanding shared their perspectives with less knowledgeable students.

The qualitative analysis of message board content reveals student interaction that is consistent with social construction of knowledge as understood in a Vygotskyan framework. When given opportunities to explore their own understanding with other students, some actively question their ideas, while others with a more expert view use the language and ideas of others to articulate that view. The authors find, therefore, that message boards are most effective when students with a broad range of conceptual development participate in discussion, actively sharing experiences and ideas, and questioning their own understanding and that of others throughout the interaction. The design of environments and prompts that support and encourage scaffolded interaction should be the focus of future research.

References

Arhar, J., Holly, M., & Kasten, W. (2001). Action research for teachers: Traveling the Yellow Brick Road. Upper Saddle River, NJ: Merrill Prentice Hall.

Becker, D. A., & Dwyer, M. (1998, September). The impact of student verbal/visual learning style preference on implementing Groupware in the classroom. Journal of Asynchronous Learning Networks, 2(2), Article 4. Retrieved October 10, 2003, from http://www.aln.org/publications/jaln/v2n2/pdf/v2n2_becker.pdf

Bennett, G. & Green, F. P. (2001). Student learning in the online environment: No significant difference? *Quest, 53*(1), 1-13.

Berk, L. E., & Winsler, A. W. (1995). Scaffolding children's learning: Vygotsky and early childhood education. Washington, DC: National Association for the Education of Young Children.

Black, T. (1999). *Doing quantitative research in the social sciences: An integrated approach to research design, measurement, and statistics.* London: Sage.

Blum, K. D. (1999, May). Gender differences in asynchronous learning in higher education: Learning styles, participation barriers and communication patterns. *Journal of Asynchronous Learning Networks*, *3*(1), Article 5. Retrieved October 10, 2003, from http://www.aln.org/publications/jaln/v3n1/pdf/v3n1_blum.pdf

Bodzin, A. M., & Park, J. C. (1998, September). A study of preservice science teachers' interactions with a Web-based forum. *Electronic Journal of Science Education, 3*(1), Article 3. Retrieved October 10, 2003, from http://unr.edu/homepage/jcannon/bod/bodzin.html

Bostock, S. J. (1998). Constructivism in mass higher education: A case study. *British Journal of Educational Technology, 29*(3), 225-240.

Brooks, J. G., & Brooks, M. G. (1999). *In search for understanding: The case for constructivist classrooms.* Alexandria, VA: Association for Supervision and Curriculum Development.

De Simone, C., Yiping, L., Dehler, C., & Schmid, R. F. (2000, April). *A distance education course: A voyage using computer-mediated communication to support meaningful learning.* Paper presented and the annual meeting of the American Educational Research Association, New Orleans, LA.

Hegngi, Y. N. (1998, April). *Changing roles, changing technologies: The design, development, implementation, and evaluation of a media technology and diversity on-line course*. Paper presented and the annual meeting of the American Educational Research Association, San Diego, CA.

Hendry, G. D., Frommer, M., Walker, R. A. (1999). Constructivism and problem-based learning. *Journal of Further and Higher Education, 23*(3), 359-371.

Hewitt, P. (1993). *Conceptual physic* (7th ed.). San Francisco: Harper Collins.

Harasim, L. (1993). Collaborating in cyberspace: Using computer conferences as a group learning environment. *Interactive Learning Environments, 3,* 119-130.

Hoadley, C. M., & Linn, M. C. (2000). Teaching science through online, peer discussions: SpeakEasy in the knowledge integration environment. *International Journal of Science Education, 22,* 839-857.

Hodson, D., & Hodson, J. (1998). From constructivism to social constructivism: A Vygotskian perspective on teaching and learning science. *School Science Review, 79*(289), 33-41.

Jonassen, D., Davidson, M., Collins, M., Campbell, J., & Hang, B. B. (1995). Constructivism and computer-mediated communication in distance education. *American Journal of Distance Education, 9*(2), 7-26.

Lawson, A. E., & Johnson, M. (2002). The validity of Kolb learning styles and neo-Piagetian developmental levels in college biology. *Studies in Higher Education: 27*(1), 79-90.

Penner, D. E. (2001) Cognition, computers, and synthetic science: Building knowledge and meaning through modeling. In W. Secada (Ed.), *Review of research in education* (pp.1-36). Washington, DC: American Educational Research Association.

Rowntree, D. (2003). Back to the future with distance learning—From independent learning to interdependence? Retrieved October 13, 2003, from http://www-iet.open.ac.uk/pp/D.G.F.Rowntree/future_dl.htm

Ruchti, W., & Odell, M. (2002, February). *Comparison and evaluation of online and classroom instruction in elementary science teaching methods courses.* Paper presented at the 1st Northwest NOVA Cyber-Conference, Newberg, OR. Retrieved October 10, 2003, from http://nova.georgefox.edu/nwcc/arpapers/uidaho.pdf

Stage, F. K., Muller, P. A., Kinzie, J., & Simmons, A. (1998). *Creating learning centered classrooms. What does learning theory have to say?* (Report No. EDO-HE-98-4). Washington, DC: ERIC Clearinghouse on Higher Education. (ERIC Document Reproduction No. ED422777)

Sutherland, P. (1999). The application of Piagetian and neo-Piagetian ideas to further and higher education. *International Journal of Lifelong Education, 18*(4), 286-294.

Tobin, K., Tippins, D. J., & Gallard, A. J. (1994) Research on instructional strategies in teaching science. In D. Gabel (Ed.), *Handbook of research on science teaching and learning* (pp. 45-93). New York: Macmillan.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes.* Cambridge, MA: Harvard University Press

Wanderslee, J., Mintzes, J., & Novak, J. (1994). Research in alternative conceptions in science. In D. Gabel (Ed.), *Handbook of research on science teaching and learning* (pp. 177-210). New York: Macmillan.

Wolcott, H. (1994). *Transforming qualitative data.* Thousand Oaks, CA: Sage.