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Teaching science through online, peer discussions: SpeakEasy in the Knowledge Integration Environment

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Can students learn science from a carefully designed online peer discussion? This research contrasts two formats of contributed comments - historical debate and narrative text - and assesses the impact of an asynchronous discussion on student understanding of the nature of light. Students discuss the question: Why do paint chips look different colours in the hardware store than they do at home? We find that students gain integrated understanding of the nature of the colour from both discussion formats. The historical debate format succeeds for more students in part because the alternative views are more memorable and in part because the debate format models the process of distinguishing ideas. We discuss how online, asynchronous peer discussions can be designed to enhance cohesive understanding of science.

Introduction

How can innovative online discussion tools improve science learning? We investigate the design and impact of the SpeakEasy discussion tool on eighth graders understanding of the nature of colour. This topic was taught solely in the online class discussions. We investigate the impact of online asynchronous discussion in general and two formats for contributed comments in particular on student knowledge integration.

Each discussion started with contributed comments articulating the views on the nature of the colour held by Kepler and Newton. In one set of online discussions we attributed these comments to Kepler and Newton thus dramatizing the historical 'debate' between these two scientists. In the other set of discussions, these same comments were contributed by online guides using a narrative text format. The contributed comment formats both contrasted historical and normative views of the topic. The narrative format resembled accounts of the nature of colour in a typical science text. The historical debate format resembled the boxed summaries featuring well-known scientists found in many science textbooks.

Online discussions can be designed to promote knowledge integration (see Hsi 1997) following the tenets of Scaffolded Knowledge Integration (Linn and Hsi 1999). Research to date shows how discussions alert students to the varied views of a topic. The current study also seeks to show how discussions might encourage students to develop more cohesive views.

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Knowledge integration is the process of introducing new ideas to the mix of views held about a science topic, considering how the new ideas connect to prior knowledge, sorting out alternatives and, reaching a coherent, robust view of the topic (Linn *et al.* 1994, Linn 1995). To build coherence, students may reconsider prior views, distinguish among alternatives, develop new insights linking prior and introduced ideas, seek new information, promote some ideas over others, coalesce previously distinct notions, or restructure ideas to enhance connections. To increase robustness students may apply new ideas to personally-relevant problems, expand the breadth of application of ideas about a topic distinguish among scientific topics, link topics a varied levels, and identify limitations of the current perspective on a topic.

In this study of the nature of colour, we found that students came to science class with a rich, diverse set of ideas. For instance, they would bring personal experiences with looking at colours like 'white paper looks red under red light', 'yellow sunglasses make everything look yellow', 'in the dark, colours fade', or 'I look weird under fluorescent lights'. Students also frequently recall experiences with prisms and lenses, noting that 'prisms make a rainbow' or that 'glasses let you see colours better'. In addition, students often remark that colours fade or change over time when exposed to sun or chemicals like bleach.

The online discussion activity on the nature of the colour in this research sought to encourage knowledge integration in three ways. Firstly, the activity introduced the ideas of Newton that pilot work showed would be new to over 75% of the students. Secondly, the discussion modelled the process of knowledge integration in this topic area by distinguishing the views of Newton and Kepler, encouraging students to follow a similar process. Thirdly, the activity supported participants in engaging in knowledge integration by rewarding students for making at least three comments, encouraging students to contribute to the discussion regularly and making it likely that students would comment on each other's ideas.

Learning from peer discussion

Many research investigations demonstrate that peer discussion adds value to classroom instruction and recent perspectives on learning highlight the importance of peer discussion. These views offer several mechanisms to explain why peer discussion contributes to the learning of complex material but also leave questions about the unique contribution of peer discussion unanswered.

Early philosophical descriptions of instruction featured variations on Socratic dialogues to encourage students to articulate instructed ideas, to reveal weaknesses in arguments and to make connections across situations. Dialogues between teachers and students in classrooms often have the goal of making student ideas visible. The mechanism behind these recommendations is that dialogues model the process of sorting out our ideas.

In some courses, like law, these dialogues are used to award grades creating an atmosphere of competition. In other courses, the teacher wants to know the diverse views of students and to stimulate students to distinguish among their views (e.g. Minstrell and Stimpson 1992) creating a collaborative atmosphere. Online discussions also can potentially make students' ideas visible and support collaboration or competition. In designing SpeakEasy we included features, like an option to make anonymous contributions to estalish a collaborative, safe environment, not a competitive environment. Collaboration supports our view of knowledge integration as a process of building on and sorting out diverse ideas. Students model their thinking for other students in the online discussion.

Interactions between teachers and students in large or small groups support collaboration when the teacher takes the role of coach, encouraging students to analyse ideas, reflect on alternatives and develop criteria for selecting one idea over another. Van Zee and Minstrell (1997), for example, describe learning conversations where students jointly develop arguments for alternative ideas. In our SpeakEasy research we model the process of considering alternatives with the contributed comments and the design of the discussion question itself. Here, we encourage that teacher modelling of the process of making sense of science is enacted in the online format.

Designing discussion topics that lead to collaborative ideas or online interactions remains a challenge. Bloom (1976) noting that classroom interactions often featured questions that required only the recall of text information, advocated asking comparison and evaluation questions to stimulate collaborative discussion. Hsi (1997) researched online discussion topics and found that students responded best to questions that connected science to practical problems such as selecting a pan for baking brownies or designing a solution for improving the lighting in the school multi-purpose room. In our SpeakEasy research we selected a topic that involved comparison and evaluation in the context of a practical problem. We asked students to explain why paint chips look different at the hardward store than they do at home or when the paint is applied to the wall.

Peer to peer discussion can extend teacher-led discussion in a variety of ways. Research has shown that both competitive and collaborative discussion can motivate students (Cohen 1995, Johnson and Johnson 1983, Slavin 1983). Research suggests that students learn more when the discussion group holds heterogeneous ideas and when students can both ask questions and give answers to questions (Webb 1995). In online discussion, more students participate if the group is heterogeneous, comes from different classrooms, runs for about four weeks and has a size of about 15 students (Hsi 1997). To encourage collaborative online discussion using SpeakEasy we randomly selected students to form groups of 11 to 15 students, drawn equally from multiple classrooms and from both sexes. Our discussion ran for about 4 weeks.

When students respond to a challenge or problem in a SpeakEasy discussion they explain their ideas. If peers comment on these ideas, students might reflect and revise their views. Cycles of response, reflection and revision of ideas support the process of knowledge integration and can lead to a more coherent understanding of science. We explore this possible impact of SpeakEasy by examining student ideas before and after discussion of the nature of colour. In addition, we look at the relationship between participation patterns, such as the number of times students revisit the discussion and learning outcomes.

Learning in a social context

Dewey (1901) argued that all learning is social and subsequent theorists have articulated benefits and mechanisms for the social context of learning (Palincsar and Brown 1984, Vygotsky 1978). One tenet of scaffolded knowledge integration is to enable students to learn from each other. In a social context students can contribute new ideas as well as provide feedback on the ideas of others. The feedback students provide to their peers captures the norms and standards they hold. Peers can provide hints and offer alternatives that help students make sense of their ideas. Vygotsky argued that a more capable peer can stimulate students to learn in their zone of proximal development - a zone the student might not access when learning alone.

In our work with SpeakEasy we enable students to seek help from peers by asking questions and to provide comments on the contributions of others. Students chose where to make comments. They may be able to serve as a more able peer for some comments while receiving help from another peer on one of their ideas. These discussions may support multiple zones of proximal development. From our knowledge integration perspective, a SpeakEasy peer-to-peer discussion elicits a broad range of ideas about a topic enabling students to distinguish among ideas they might not consider on their own. In addition, SpeakEasy discussions capture the reasoning students use to distinguish ideas and therefore model the process of linking and sorting out ideas from many perspectives.

In the classroom, we conduct activities to help students establish group norms for knowledge integration (see Linn and Clark 1997). As a result the SpeakEasy discussion also captures the group interpretation on what constitutes a valid argument.

From the perspective of Vygotsky, SpeakEasy discussions could support multiple zones of proximal development provided students (a) can ask questions and get answers; (b) can find contributions to critique; and (c) can respond to commentary on their contributions. The SpeakEasy discussion is more open-ended than reciprocal teaching (Palincsar and Brown 1984) but serves a similar function. In SpeakEasy discussions students can be seen as participating in a cognitive apprenticeship as described by Brown *et al*. (1989). Our research sheds light on the social context of learning by studying learning that occurs solely in an online discussion.

Models of knowledge integration

In SpeakEasy discussions students can observe the process of knowledge integration among peers and, in this research, also observe how two scientists responded to each other's ideas historically. This observing and contributing resembles the legitimate peripheral participation that Lave and Wagner (1991) show can improve understanding of a complex domain. This modelling also implements the tenet of Scaffolding Knowledge Integration which says to make thinking visible (see Linn 2000).

Equity and discussion

Recently, researchers have highlighted the patterns of participation in class discussions, noting that more males than females participate even when teachers seek to make discussion equitable (Sadker and Sadker 1994). Detailed study in classrooms reveal that only 15-20% of students participate in class discussion. Males participate more, in part, because they are more likely to shout out contributions without teacher permission. Even in small groups, males often dominate and reinforce stereotypes about who succeeds in science.

In contrast, well-designed, asynchronous electronic discussions can engage most students (up to 90%) in class discussion while also enabling males and females to participate equally (Hsi 1997, Hsi 1992). Design decisions such as allowing students to participate anonymously increases the rate of participation. In addition, in electronic discussion, students make longer comments and support their views with multiple warrants (Hsi 1997). In this research, we investigate whether, for new topics and the SpeakEasy discussion tool, these patterns of participation hold.

Research plan

In summary, we investigate the benefits of online, asynchronous discussion as the sole form of instruction on the topic of the nature of colour. We establish 15 separate discussion groups drawn from six middle school classes. Discussions start with contributed comments in either the historical debate or narrative text format. We explore how participation patterns impact learning and study the equity of participation.

Methods

In this research we study one online discussion about the nature of colour that formed part of the Computer as Learning Partner energy curriculum. The 15-year long study is part of a comprehensive research programme (Linn and Hsi 1999). We studied contributions and learning from the second topic students discussed online, so students were already familiar with the technology.

Students

Eighth grade students from six science classes of 30 students each taught by the same teacher participated in a total of 15 randomly assigned discussion groups. Each discussion had equal numbers of males and females, students from multiple classes and students with a range of pre-test perspectives. All students studied science every day in a classroom with 16 computers. Their other science assignments also took advantage of computer technology.

Discussion assignments

Students participated in the SpeakEasy discussion as homework. The topic of light was not introduced in class until after the online discussion of the nature of colour was completed. The problem students discussed, the changing colour of paint strips, is shown in figure 1.

Students were required to contribute three or more comments to the discussion during the four-week period and were graded on the use of evidence in their comments but not on the ‘correctness’ of their ideas. The teacher encouraged students to build on their own ideas and experiences following the Scaffolded Knowledge Integration framework.

Topic title	Topic description
Why do the paint chips look different under different lighting?	"I recently decided to paint my living room. I went to the hardware store and picked out three colors in the store, and took samples of those colors home. When I got home that night, I took a look at the paint samples again. One of them seemed a lot more greenish than I had remembered in the store. In the morning, I looked at them in daylight, and the colors looked slightly different again. The web site I found about picking paint colors (http://www.todayshomeowner.com/planner/articles/paint/03.94.50.html) says to always look at the paint under the same kind of lighting as where it will be used. How are light and color related? Why did the colors look different in the store's fluorescent lighting, at home under regular light bulbs, and in sunlight? Be sure to support what you are saying with evidence and examples."

Figure 1.

To complete the homework assignment students could access the class computer network before school, after school, during lunch, when they finished other class assignments, or form a remote location like the library, home, or community centre. Most students contributed from school.

SpeakEasy discussion environment

We designed the SpeakEasy to scaffold student discussion by providing multiple representations of discourse and emphasizing social information in the interface. SpeakEasy is an asynchronous, structured multimedia bulletin board system which may be accessed via the world wide web. The system poses a problem that is related to the students' everyday experiences (see figure 1). Student comments are generally represented by an icon of the students' face, or students can choose to remain anonymous. Any comment may be linked to other resources on the world wide web. Clicking on a face allows the participant to read that comment.

The opinion area (figure 2) contains students' overall reaction to the topic. A topic author may include elements which must be voted on (numerically, using a Likert scale) as part of the opinion. When students first enter a topic, before seeing any other student comments, or items contributed by discussion authors, they must state their initial opinion. A student may provide only one opinion but can revise it at any time.

The second area within a topic is the discussion area (figure 3). The discussion area represents back-and-forth discussion. Students may make as many comments as they wish to the discussion area. Once completed, comments cannot be changed, since editing comments once someone else has responded to them may obliterate the context needed to understand the responses. Each discussion started with comments contributed by the discussion authors. When students respond to other comments, they are prompted to categorize their comment with a semantic label. This study uses the categories 'and', 'or', 'but', 'i.e.' and '?'. In addition, students provide a brief subject heading for their comments. The semantic labels, subject heading and face icons are displayed in outline form. Thus, students can see the overall structure of the discussion before reading individual comments. They can pinpoint areas of controversy, areas of agreement, items which generate questions and the contributions of specific individuals.

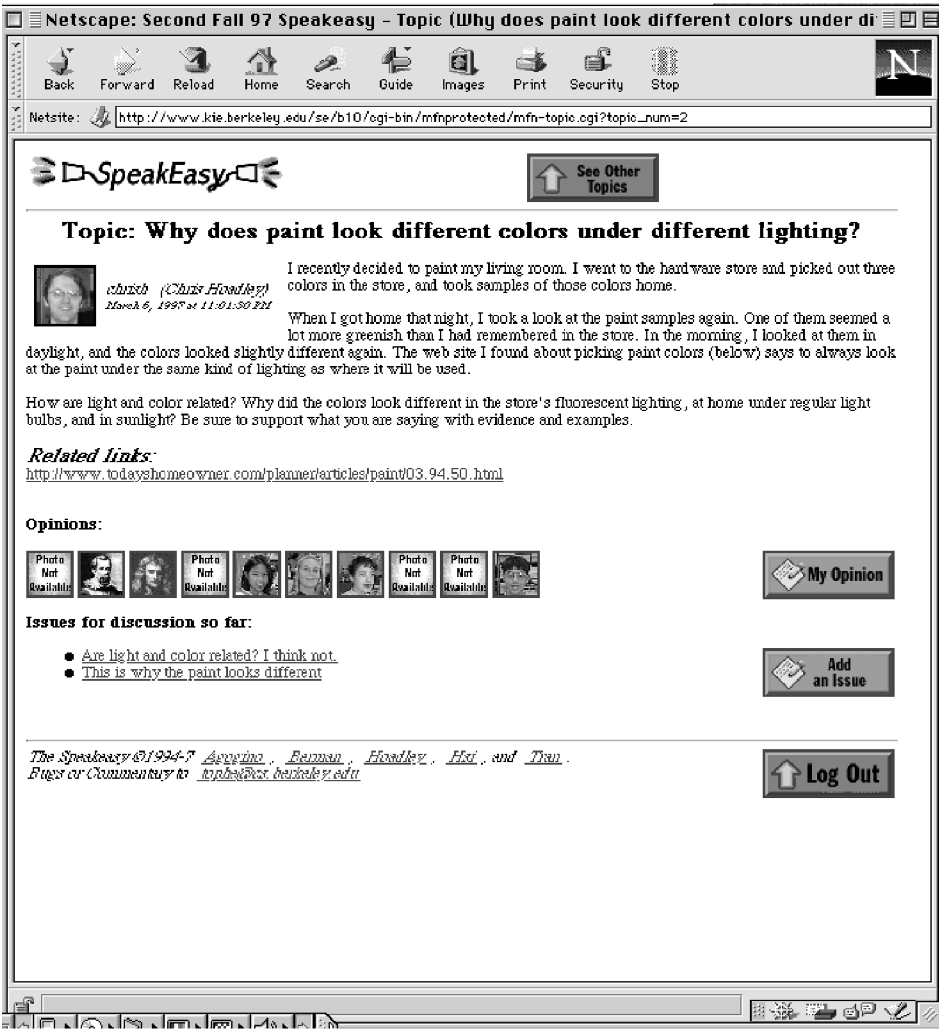

Figure 2. SpeakEasy opinion area.

SpeakEasy addresses some of the difficulties in classroom discussion. The representation of the discussion enables students to revisit ideas and encourages students to integrate disparate conceptions, either their own or others. Prompting students for overall opinions and requiring students to categorize their comments spurs a high level of reflection. Students often have difficulty reconsidering their own explanations or seeing how they fit in with the ideas of others in the excitement of class discussion. Finally, grading based on the evidence and support in one's comments rather than the 'correctness' instills important scientific values.

Discussion conditions

In this historical debate condition, comments appeared in the opinion area as if Newton and Kepler were participating in the discussion. Comments supporting

Figure 3. New discussion areas.

the theories that light merely carries colour and that light is composed of colour were linked to homepages about the scientists (see figure 4). In the narrative text condition, a guide made comments in the opinion stating that, in the past, these two theories were held (but not by whom) (see figure 5).

In the historical debate condition, both scientists contributed to the discussion. In the narrative text condition these comments were made anonymously.

SpeakEasy discussion data

Students' contributions to SpeakEasy were identified by author and the time of contribution. In addition, every comment read by each student was identified by reader and time of reading. From this information we computed the number of separate days that each student participated in the discussion, the number of comments made and the number of unique comments read (including the reading of one's own comments).

Student comments were read and graded by the teacher. In grading participation, points were assigned for each comment based on the length and thoughtfulness (i.e., whether the comment was on-task, provided an explanation or justification, was at least one sentence long, and so on). Full credit was given for

```
chrish (Chris
March 6, 19XX at 11:03:53
I think liaht chanoes the color of thinas. For instance. at sunset
sun is red. evervthina looks reddish. So mavbe the different
different colors to the

iohannesk (Johannes
March 6. 19XX at 11:37:37
I believe that liaht can carrv color. So for instance. if liaht
through colored glass, it picks up the color and carries it to the
vou're seeina. What haooened here is that the store liahts were
some color from their covers that chanaed the color of the oaint. At
vour lamo shades added color that chanaed the color of the oaint.
daylight let you see the true color of the paint because it wasn't
anv colors at

isaacn (Isaac
March 6, 19XX at 11:52:20
The reason the oaint looked different colors is because liaht is made
manv colors. When these colors bounce off obiects into vour eve. vou
color of the obiect. Under white davliaht. the oaint reflects
colors. But artificial light does not contain as many colors as
Thus. the obiects will reflect different colors to vour


The followina are issues and their resoective

      iohannesk (Johannes
      03/06/XX  11:46:39
      Are liaht and color related? I think

            isaacn (Isaac
            03/06/XX  11:55:52
            BUT : liaht is made of manv
                  no. liaht doesn't carrv color. it's made of colors.
                  whv the white liaht of the sun can be solit into
                  colors of the rainbow bv a water droo or a

      isaacn (Isaac
      03/22/XX  09:16:05
      This is whv the oaint looks

            iohannesk (Johannes
            03/22/XX  09:19:31
            BUT : No. sunliaht doesn't have colors
                  Sunliaht doesn't have colors in it: the onlv color of
                  is white! It can carrv colors. thouah. So for
                  fluorescent light in the store may have picked up some
                  like from the olastic case around the liaht. The
                  out of the olastic. The liaht carried the color to the
                  chio. The color carried bv the liaht is added to the
                  the paint

                  isaacn (Isaac
                  03/22/XX  09:22:43
                  BUT : Here's an example why that's not
                        If I have white oaoer and black oaoer. the
                        reflects all the colors and black absorbs them
                        shine a colored liaht (red. for instance) on
                        pieces of paper, the black paper still looks
                        the white oaoer looks red. That's because
```

Figure 4. Text of comments in historical debate condition of the paint chips discussion.

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The following are opinions on this topic:

chrish (Chris Hoadley)
March 6, 19XX at 11:03:53 PM
I think light changes the color of things. For instance, at sunset when the
sun is red, everything looks reddish. So maybe the different lights give
different colors to the paint.

mildredc (Mildred the Cow)
March 6, 19XX at 11:52:20 PM
Two hints from history: in the past there have been two theories about light
and color. One idea is that light can carry color. So for instance, if light
shines through colored glass, it picks up the color and carries it to the
object you're seeing. According to this idea, wheat happened here is that
the store lights were carrying some color from their covers that changed the
color of the paint. At home, your lamp shades added color that changed the
color of the paint. Only the daylight let you see the true color of the
paint because it wasn't carrying any colors at all. Another theory is that
light is made up of many colors. When these colors bounce off objects into
your eye, you see the color of the object. According to this idea, under
white daylight, the paint reflects certain colors. But artificial light does
not contain as many colors as sunlight. Thus, the objects will reflect
different colors to your eye.

The following are issues and their respective opinions:

    Anonymous (no name)
    03/06/XX__11:46:39 PM
    Are light and color related? I think not.

        Anonymous (no name)
        03/06/XX__11:55:52 PM
        BUT : light is made of many colors
            no, light doesn't carry color, it's made of colors. This is
            why the white light of the sun can be split into the many
            colors of the rainbow by a water drop or a prism.

    Anonymous (no name)
    03/22/XX__09:16:05 AM
    This is why the paint looks different

        Anonymous (no name)
        03/22/XX__09:19:31 AM
        BUT : No, sunlight doesn't have colors in it
            Sunlight doesn't have colors in it; the only color of light
            is white! It can carry colors, though. So for instance, the
            fluorescent light in the store may have picked up some color,
            like from the plastic case around the light. The color came
            out of the plastic. The light carried the color to the paint
            chip. The color carried by the light is added to the color of
            the paint chip.

            Anonymous (no name)
            03/22/XX__09:22:43 AM
            BUT : Here's an example why that's not true
                If I have white paper and black paper, the white
                reflects all the colors and black absorbs them all. If I
                shine a colored light (red, for instance) on the two
                pieces of paper, the black paper still looks black. But
                the white paper looks red. That's because it's
                reflecting all the colors of light that reach it, where
                the black absorbs them all.
```

Figure 5. Text of comments in narrative text condition of the paint chips discussion.

thoughtful answers whether or not they reflect normative ideas. Some extra credit could be earned by making additional comments. Most students earned full credit for the required three comments.

Colour assessment

To assess student understanding of the nature of colour, we gave a quiz after the discussion and analysed students' initial opinions when they entered the discussion. In both cases, students explained why the paint chips looked different colours under fluorescent lights, regular incandescent lights and sunlight.

We scored student responses by coding all the ideas students incorporated into their explanation. We refer to students' ideas as facets, following Hunt and Minstrell (1994). The facets students used and their frequencies are shown in figure 6. Students typically relied on several facets on the pre-test consistent with our view that students bring multiple ideas to science class. To assess

Frequency distribution for facet
Split By: pre-post

	Total Count	pre Count	post Count
B	b 146	76	70
CL	36	19	17
F	11	5	6
LCC	20	11	9
LIC	40	13	27
O	71	45	26
VL	65	28	37
VR	51	37	14
Total	440	234	206

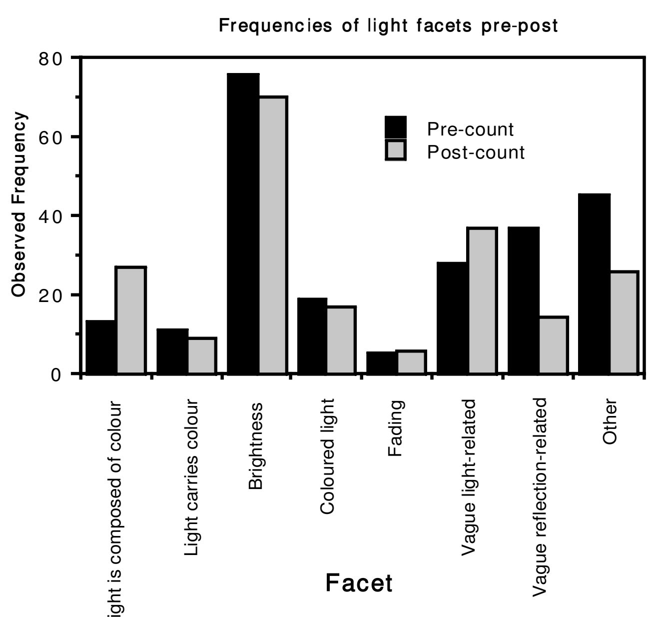

Figure 6. Facet frequencies pre- and post-discussion.

Score	Explanation
6	{LIC} Light Is composed of Colour. Describes light spectrum or how multiple colours of light are selectively reflected by materials.
5	{CL} Coloured light. Description of coloured light without spectral explanation. OR {VR} Vague Reflection. Reflection related explanation which does not describe light spectrum.
4	{B} Brightness. Explanation based on the brightness of light changing the brightness of colours. OR {F} Fading. Describes how coloured materials fade over time or with exposure to light, heat, or weather.
3	{VL} Vague Light related. Different light leads to different colours, but no further explanation.
2	{LCC} Light Carries Colour. Colour is a property or substance which may be carried to an object by light. OR {O} Other facets (e.g., the store switched the paint chips to sell more paint).
1	Any attempt which contains no facets listed above (e.g. "It just does," or simple restatement of the problem).

Figure 7. Facet correctness score.

progress in understanding light we formulated a facet 'correctness' score based on the most sophisticated idea expressed by the student. The facet correctness-coding scheme appears in figure 7.

To assess response to the SpeakEasy discussion we administered a post discussion survey asking students to rate SpeakEasy relative to other class activities and to indicate what theories and attributions they recalled from the discussion. In addition, we interviewed 23 students about what they liked best and least about SpeakEasy.

Results and discussion

Overall, students enjoyed using SpeakEasy and contributed productively to the discussion. Students made between 1 and 22 comments with an average of 5.3 (SD = 3.1) comments, well in excess of the required three comments. Students read between one and 104 comments with an average of 20.8 (SD = 14.3) unique comments read. Each comment was read by an average of four students. On average students logged on in between one and 11 days during the four week discussion (M = 3.3; SD = 1.9). Only seven of the 180 students failed to participate in the discussion. Students rated the discussion, on average, between three and four on a five-point scale. Of the five types of class activities (class discussion, internet research, experiments with real-time probes, computer simulations and online discussions) 15% of the students preferred the online discussion. Overall, students participated but considered the discussion less interesting than other parts of science.

To determine the effect of the discussion condition we first establish that the randomly assigned groups are equal. Comparing pre-test scores, the two discussion conditions are equal on the pre-test ($M_{Newton-Kepler} = 3.5$, $SD_{Newton-Kepler} = 1.4$; $M_{Control} = 3.7, SD_{Control} = 1.4$; $F(1,148) = 1.3$, $p = 0.25$). In addition, the starting ideas contributed to the discussions did not influence the final outcomes. An ANOVA ($F(1,13) = 0.976$, $p = 0.34$) yielded no significant differences between the nine discussions initially containing the correct answer and the six discussions which did not, on the mean facet correctness score. Additionally, an ANCOVA ($F(1,13) = 1.127$, $p = 0.28$) on total number of facets expressed in the pretest scores yielded no significant differences in mean facet correctness. Likewise, an ANCOVA on ($F(1,13) = 1.84$, $p = 0.19$) total number of supports (evidence and examples) cited in the discussion yielded no significant effect of discussion group.

Looking at participation in the discussion we mainly see similarities. During the discussion, students in the historical debate condition and the narrative text condition read and wrote comments equally ($F(1,158) = 0.10$, $p = 0.75$; $F(1,161) = 0.00$, $p = 0.98$). They were equally likely to be anonymous ($F(1,158) = 0.08$, $p = 0.78$). Students in the historical debate condition logged in over significantly more days ($F(1,161) = 5.07$, $p = 0.03$), a finding we will discuss below. Analysis by discussion group revealed the same pattern: groups were equal for mean comments made, comments read, average anonymity ratios and supports cited. For groups in the historical debate condition motivated an increase in days logged in ($F(1,13) = 7.730$, $p = 0.02$), consistent with the finding for students reported above.

Looking at learning using the facet correctness score we find that all students made significant pre-test to post-test progress (pre-test $M = 3.5$; $SD = 1.4$; post-test $M = 4.2$; $SD = 1.2$; ANOVA $F(1.149) = 17.5$; $p < 0.01$). Students in the historical debate condition made more progress than students in the narrative text condition, as shown in figure 8 (post-test mean historical debate $= 4.4$; post-test mean narrative text $= 4.0$; $F(1,148) = 5.2$; $p < 0.02$). The greater success of

	group	FacetPost	Comments Made	Comments Read	Days Logged In	percentage of anon. comments	supports cited	Contributing
1	15	5.000	4.70	21.50	2.90	.40	7.600	10/11 (91%)
2	**4**	**4.917**	**4.25**	**14.33**	**2.75**	**.35**	**3.583**	**12/12 (100%)**
3	**1**	**4.727**	**5.25**	**23.75**	**3.83**	**.35**	**6.833**	**12/12 (100%)**
4	**5**	**4.667**	**4.08**	**17.82**	**3.09**	**.34**	**3.500**	**12/12 (100%)**
5	8	4.455	7.17	26.83	3.33	.56	5.500	12/12 (100%)
6	**3**	**4.364**	**8.36**	**34.25**	**4.83**	**.26**	**8.682**	**12/12 (100%)**
7	**7**	**4.364**	**4.91**	**22.36**	**3.73**	**.30**	**7.273**	**11/12 (92%)**
8	**2**	**4.125**	**4.42**	**17.83**	**3.83**	**.30**	**4.167**	**12/12 (100%)**
9	10	4.100	4.82	20.09	3.46	.33	2.909	11/11 (100%)
10	14	4.000	4.67	22.67	2.78	.31	6.944	9/10 (90%)
11	9	3.900	5.70	23.10	2.90	.20	3.700	10/10 (100%)
12	**6**	**3.833**	**5.17**	**16.92**	**3.58**	**.46**	**5.083**	**12/12 (100%)**
13	11	3.750	4.62	16.22	2.89	.22	4.938	10/10 (100%)
14	13	3.636	6.00	21.36	2.82	.50	7.455	10/11 (91%)
15	12	3.000	4.38	14.33	2.89	.27	3.875	8/11 (73%)

Bold faced discussions are in the Newton-Kepler condition; other discussions are in the Mildred (Con condition.

Figure 8. Participation and learning, by discussion within condition.

students in the historical debate condition could be due to better understanding of the ideas contributed to the discussion or to the increased ability to integrate the ideas into an account of the nature of colour.

Results from the post discussion survey show that students in the historical debate recall the theories from the discussion better than students in the narrative text condition ($F(1, 139) = 2.9$, $p < 0.01$). Students in the historical debate condition attribute the theories to the scientists more often than students in the narrative text condition attribute comments to the guide ($F(1, 161) = 14.6$, $p < 0.01$). Thus, one benefit of the historical debate condition is that students remember the two perspectives on the nature of colour better. The greater recall of the two theories in the historical debate condition appears to stem from the salience of the attribution of these theories to Newton and Kepler.

Students in the narrative text condition recall the theories less often and also rarely recall who contributed them to the discussion. Indeed, only one student recalled that the guide contributed the theories in the narrative text format while 15 students recalled that Newton or Kepler contributed the theories in the historical debate condition. In each condition, 23 students recalled at least one of the theories but could not identify the contributor. Thus, adding the scientific attribution enables 60% more students to recall the theories. Overall, however, only 62 of the 180 students recalled the theories when asked on the post discussion survey.

Recalling the attributions for the two theories also probably helps students distinguish the views. In contrast, students who recall the two theories in the narrative text format appear to see them as among the views introduced to the discussion rather than seeing them as both being held by the guide. Since the guide also takes the role of giving hints and prompting for elaboration it is reasonable to assume that students accord little significance to the guide and instead focus on the ideas.

Thus, students in the historical debate condition had better recall of the theories contributed but only one-third of the students, overall, recalled these contributions. All students read comments from peers and may have learned from these interactions.

Adding new ideas

The most common benefit of SpeakEasy identified by interviewed students was that they could hear the opinions of others. This finding reinforces comments by students studied by Hsi (1997) who expressed surprise that their peers in science class held different opinions about science topics. While students regularly participate in class discussions they do not conclude from this experience that classmates hold alternative views. However, in online, asynchronous discussions students frequently recognize that other students hold alternative views.

One difference between class and online, asynchronous discussion is that students can read comments without also wondering what to say next and that students can compose their contributions to discussion more carefully. These student comments in the interviews help explain why SpeakEasy revealed more student ideas to peers than class discussion does:

Student: 'You can express what you say. Like you can say what like without anybody like being like, oh, that's not right, you know? You can like say something that you totally believe in and people don't have to like (it). It's easier to write than I think it is to speak ... everyone says the answer and you say no, then I mean then you're like then it must be yes then. You know? Because it makes you put your own opinions ... and you can like have conversations ... so you can basically say what you want to and what you feel'.

Student: '... it's easier to write down, but sometimes like everybody has different opinions ... right now you feel comfortable with everybody. You can like tell without anybody like being mean or anything and so, not really in this class. But it is, I would think like for some shyer people, probably would be easier for them ...'.

Student: 'Well, like some of the subjects are kind of hard for me to understand ... about ... something that I don't really know too much about, so because it takes me a long time before I can actually go on and put my own theory - I have to think a lot about it. That's something. Maybe I would like it to be a little bit easier ...'.

Student: 'I come back later and more prepared to answer it. I'd give my best opinion, but I would like, first, go home and think about it more'.

In the SpeakEasy discussion students reported that they had the opportunity to hear more ideas about the nature of colour than they would in a typical class with text and a discussion. Students in both conditions learned ideas from peers. Students in the historical debate condition could also contrast peer and scientist comments whereas in the narrative text discussion the scientist comments were not singled out or accorded special status. The attribution of theories to Kepler and Newton privileged them in this historical debate condition, probably contributing to greater learning in that condition.

Model the process of distinguishing ideas

Besides learning more ideas about the nature of colour, students learning from online discussion also observe others distinguishing ideas and selecting among them. Students in the historical debate condition may have benefited from the opportunity to observe Newton and Kepler responding to each other's ideas. Observing that scientists, like students, can disagree and seeing how scientists respond to the idea of other scientists may have spurred students in the historical debate condition to spend more time and energy distinguishing ideas. This may account for the significant difference mentioned earlier between the two conditions on days logged into the discussion ($F(1,161) = 5.1$, $p < 0.03$). In interviews, respondents comment on how students and scientists disagree, illustrating the potential of the discussion to help students learn to compare and distinguish ideas:

[I mainly remember] ... disagreeing.

Like one person would say, well, 'Why don't they come up with a natural light?' and another person would say, 'well, because, it's no one wants to, no one's looking at it ... and it makes it easier that way to write stuff ... everyone thinks'.

'A lot of people were writing about shadows - to me it looks foolish - um, I just tried to look at all of them ... I read them top to bottom ... There was one person that was talking about prisms and did give some evidence for that type of thing'.

In summary, students appear to benefit from SpeakEasy discussion both because they become acquainted with a diverse set of ideas about the nature of colour and because they have the opportunity to observe both students and scientists modelling the process of distinguishing among diverse ideas. Students in the historical debate condition benefit more than students in the narrative text condition because they recall more of the scientists ideas and also, possibly, because they gain more insight into how scientists sort out their ideas.

Differences between discussions

The 15 discussions varied along many dimensions including overall progress in understanding the nature of colour as shown in figure 8. Only two discussion groups in the narrative text condition had average scores above the overall mean and one of those was the most successful discussion in terms of post-test performance. Only one discussion in the historical debate condition performed below the average and this discussion also had a high percentage of anonymous comments and, a low number of unique comments read. Overall, however, only days logged-in correlated with average discussion post-test score.

Research suggests that students learn more when they either ask or answer questions and are disadvantaged when their questions go unanswered (Webb 1995). When students log on to a discussion less frequently they reduce their opportunities to get answers to their questions because they do not return to read answers that might be posted.

There were significant differences between discussion groups even after the main effect of condition was statistically controlled. Given that groups were formed randomly and involved students from multiple classes, this finding underscored the many factors that contribute to the success of an online discussion. In this study and in the work of Hsi (1997) we see that discussions take on a unique character and that students succeed in discussion in part as a result of the contributions of their peers.

Facet analysis

Overall, from pre-test to post-test students cite fewer facets (see figure 7) suggesting that they develop more coherent accounts of the nature of colour. In addition, there is a general decline in the use of the non-normative facets on the post-test. Students were less likely to cite idiosyncratic reasons (found in the 'other' category) such as 'the hardware store switched the paint chips to sell more paint' or 'the paint chips weren't dry when they left the store'. Instead, more students cited the scientifically normative explanation that light is composed of colours. Although they also discussed Kepler's view of light as carrying colour, fewer students cited this model on the post-test than on the pre-test. This is consistent with the results reported by Bell and Linn (2000) where students consider two historical views of light propagation and develop a more coherent account of one view or the other.

Equity and SpeakEasy discussion

Many research studies document that a small portion of students participate in class discussion (typically 15-20%) and that of those who participate, males outnumber females. The relationship between participation in class discussion and science learning has not yet been established.

However, in this research we have shown a substantial learning effect from SpeakEasy discussion. An important difference between SpeakEasy and class discussion is that almost every student participated in SpeakEasy (see figure 8). Males and females also make equal numbers of comments, logged in equally often and used the option to be anonymous equally. Females read somewhat more comments than males, consistent with the results reported by Hsi (1997). Thus, SpeakEasy is far more inclusive than class discussion. In SpeakEasy, males and females make equal progress from pre-test to post-test (for improvement, $M_{female} = 0.49$, $SD_{female} = 1.8$; $M_{female} = 0.84$, $SD_{male} = 2.0$; $F(1, 148) = 1.28$, $p = 0.26$).

SpeakEasy enables all students rather than a select subset to participate. In addition, males and females participate equally allowing all class members to hear a diverse set of views. The opportunity to reflect prior to contribution creates a more coherent discussion than typically occurs in class and appears to enable diverse students to learn from online discussion.

Conclusions

Students can learn science ideas from a well-designed online asynchronous discussion alone. In this research, discussion succeeded in helping students learn more often when comments introduced in the discussion enact a historical debate, rather than when they follow a narrative text format. The historical debate format appears to help students learn science by making alternative views of the science topic memorable and by modelling the process of distinguishing among ideas. Further research is needed to replicate and extend this finding.

These findings support and extend research on reciprocal teaching by showing that an open-ended, reciprocal format can enhance comprehension (Palinscar and Brown 1984). They also support research by Slotta and Chi (1997) showing that self-explanations, given here in the context of responding to peers or scientists, can enhance understanding of science. The results are also consistent with the argument of those favouring apprenticeship (Collins and Brown 1991, Lave and Wenger 1991) because the scientists, as well as other students, serve as models for the process of connecting ideas.

Students learn more when they revisit the discussion on different days but, other activities such as the number of comments read or contributed do not correlate with success. Discussions also vary in overall success but this is not simply due to the presence or absence of specific ideas. From our knowledge integration standpoint, we suspect that successful discussions provide a rich collection of ideas and also illustrate how these ideas can be distinguished. Based on the greater success of the historical debate format we imagine that discussions fail when students do not get answers to their questions or lack models of the knowledge integration process. This remains an important research question.

Designing effective discussions

The research reported here and in other investigations clearly show that productive discussions need careful design. Group size of about 12, gender balance and students from diverse classes all lead to productive discussion (Hsi 1997). The option to make anonymous comments improves discussion participation (Hsi

1997, Scardamalia and Bereiter 1992). Topics that focus discussion and connect to personal experiences succeed more than broad, academic questions (Hsi 1997). Each of these design features appears to enhance discussion by enabling participants to consider multiple ideas and to respond to each other.

The success of the historical debate condition suggests a further design feature for productive discussion. Discussions benefit from articulation of alternative views and from models of the process of distinguishing among ideas. Drawing on authentic historical debates can both highlight the nature of the scientific advance and enable students to engage in the process themselves.

A continuing issue with online discussion concerns the motivation to contribute. When students are rewarded for participation they do log on and make comments but some take a minimalist stance, only logging on once. The discussion is not viewed as exciting by most students and, many attempts to motivate groups to join discussion groups fail. The most successful groups appear to be those discussing hobbies or medical conditions that are personally relevant to the participants. We need more investigations to determine ways to make science discussions similarly motivating.

Reflection

This study demonstrates that students can learn from each other. It shows that equitable opportunities for discussion can be designed. It challenges science educators to find ways to enhance the reflective nature of class discussion and to ensure that all voices are heard.

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