Computer Supported Collaborative Physics Learning: Developing Understanding of Image Formation by Lenses

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ABSTRACT

This article reports the use of a computer-supported collaborative learning (CSCL) instruction designed to help students develop understanding of image formation by lenses. The study aims to investigate how students, working in dyads and mediated by multimedia CAL programs, construct shared knowledge and understanding. The subjects were a class of 36 grade 10 students working in dyads throughout the instruction. The instruction comprised three stages, pre-test, CSCL activity, and post-test, during which students' within-dyad interactions were audio-recorded and transcribed for analysis. Three months after the instruction, some students were interviewed individually. The pre-test showed that the majority of students held the "holistic conceptualizations" of image formation (rather than the physicists' point-to-point mapping model) which they applied to give incorrect answer/explanations to the questions in the test. In general, the dyads showed overall improvement in understanding in the post-test and interviews although the improvements ranged widely. The rich qualitative data of peer interactions show that students experienced many instances of conflicts and co-construction that were conducive to the development of understanding. They also show that students' development of understanding depend not only on their prior ideas but also on (a) how they interact with each other and the ideas they invoke, and (b) the mediation by the CAL programs and the teacher. The article ends with a discussion of implications for instructional practices.

*Paper Presented at the 2000 Annual Meeting of the National Association for Research in Science Teaching, New Orleans, LA, USA, April 28 – May 1, 2000.

In school physics, instruction in lenses in optics usually entails

1. observing the images formed by spherical lenses as projected on screen and/or viewed through the lenses;
2. investigating refraction of light by cylindrical lenses using ray tracing apparatus; and
3. drawing standard ray diagrams using "construction rules" (rays along specific directions) to determine the nature (whether real or virtual, erect or inverted, magnified or diminished) and position of the image formed.

This approach aims to help students to develop understanding of image formation by lenses which they can then use to explain the workings of magnifying glass, the human eye, simple camera, etc. However, such aim is often not achieved (Goldberg & McDermott, 1987). Image formation is very difficult to understand and research has shown that students hold a range of alternative conceptions about it (Galili, 1996; Galili, Bendall & Goldberg, 1993; Goldberg & Bendall, 1992). In traditional physics instruction, the use of standard ray diagrams is often given such importance and prominence that the more basic questions of *why* and *how* images are formed are not properly addressed.

This article reports a study of the use of an alternative instruction designed to help students to develop understanding of real image formation by convex lenses. The instruction makes use of multimedia CAL programs and employs a peer collaboration strategy that encourages student discussion and reflection. As such, it is in a genre of *computer supported collaborative learning* (CSCL) which is an emerging field of study (Koschmann, 1992, 1994, 1996; O'Malley, 1995). The study investigated whether and how students, working in collaboration and mediated by multimedia CAL programs, construct shared knowledge and understanding of image formation by lenses.

Image Formation: Physicists' Explanation and Students' Alternative Conceptions

Physicists explain image formation using the *point-to-point mapping model* (Galili, 1996; Goldberg & Bendall, 1992; Galili et al., 1993). According to this model, an extended object is an assembly of object points. For real images formed by a convex lens, a cone of rays (divergent flux of light) from an object point is converged by the lens to an image point (Figure 1a). Each point on the object has a corresponding image point and the assembly of all the image points forms the image. This explains why a sharp image is captured on a screen placed in that position. If the screen is moved slightly closer to or further away from the lens, the image on the screen becomes blurred since rays from each object point are projected on the screen as a patch of light.

The point-to-point mapping model of image formation is seldom explicated in school physics. In the standard ray diagrams in most textbooks, two or three single rays are drawn along specific directions (the construction rules) from the object (represented by an arrow) to be refracted by the convex lens to form the image (Figure 1b). While it is possible to apply the notion of one-to-one correspondence between object and image points to such ray diagrams, this is seldom done, or is mentioned in passing only.

Research on students' understanding of image formation by lenses (Galili, 1996; Galili et al., 1993; Bendall & Goldberg, 1992) have identified a range of alternative conceptions held by undergraduate students, the most prevalent ones being the *holistic model* and the *"pin-hole" model*. In the holistic model, the whole image is conceptualized as parallel light rays that move through space from the object, turn upside down inside the lens and are then blocked by the screen to form an image on it (Figure 1c). According to this model, changing the screen position only affects the size of the image but not its clarity and the image remains sharp for all positions of the screen from the lens. In the “pin-hole” model, rays from the entire object converge at the optical center of the lens which become diverged on passing through the lens and are then blocked by the screen to form an image, i.e., the lens is treated as if it were a pin-hole (Figure 1d). Again, according to this model, a change in screen position will only affect the image size but not its clarity.

Theoretical Underpinnings

Collaborative Learning

For more than a decade, as a reaction to the traditional teacher-centered instruction, there has been a growth of interest and development in peer learning which has shown potential for fostering active student learning (Damon, 1984). Collaborative learning is one of the main approaches to peer learning. It involves two or more students working together on a task that neither can do prior to the collaborative engagement. According to Damon and Phelps (1989), collaborative learning provides a supportive environment that encourages students to experiment with and test new ideas. They assert that the engagement of peer collaboration is “rich in mutual discovery, reciprocal feedback and frequent sharing of ideas” and is particularly useful for tasks that require “new insights, conceptual shifts, and the development of deep knowledge structure” (p.14).

Crook (1994) suggests that collaborative learning offers three cognitive benefits: *articulation*, *conflict* and *co-construction*. He contends that students in collaboration have to articulate and make public their ideas and this helps them clarify their conceptions. To resolve conflicts when disagreement arise, students have to justify and defend their positions and this forces them to reflect on and review their understandings. When working jointly on a task, students can complement and build on each other’s ideas and incrementally co-construct shared understanding. Along similar vein, Koschmann (1994) contends that collaborative learning exposes students to multiple perspectives and interpretations and provides them with the opportunities to articulate their understandings.

The benefits of conflict and co-construction in collaborative learning are based on the Piagetian and Vygotskian perspectives of learning respectively as theoretical underpinnings. According to Piaget (1985), the benefit of peer collaboration arises from socio-cognitive conflicts from students’ divergent views and the resolution of the disequilibration engendered. Thus peer collaboration is seen as providing a useful context or vehicle for students’ personal sense-making and knowledge construction. On the other hand, the Vygotskian perspective views learning as the sharing of meaning in a social context in which language plays a crucial role. According to Vygotsky (1962, 1978), understanding needs to be first rehearsed between people (between teacher and students and between students) before it is developed within the individual as an internal process. He speaks of an “intermental” and an “intramental” plane of higher mental functioning and argues that any higher mental functioning is external before it is internal. Thus both the social and personal aspects of learning are stressed and the former gives rise to the latter through a process of internalization. The Vygotskian perspective has provided the foundation for social constructivism which has been very influential in research on learning in general and in science learning in particular.

In the Vygotskian perspective, collaborative learning is concerned with developing understanding on the intermental plane and the process is one of convergence of meaning rather than divergence of views. As Roschelle (1992) puts it, collaborative learning is “a process that gradually can lead to convergence of meaning" and the peer interactions occurring during the process enable students "to construct increasingly sophisticated approximations to scientific concepts collaboratively, through gradual refinement of ambiguous, figurative, partial meanings" (p.237).

Vygotsky's work has been very influential in research on collaborative learning which has, in recent years, shifted its focus from studying the outcome of collaboration to examining the process. The more recent studies (e.g., Mercer, 1996; Teasley, 1997; Mason, 1998; Kumpulainen & Mutanen, 1999; Wegerif et al., 1999) all emphasize the important role played by peer interactions in the development and negotiation of shared meaning and understanding.

Learning Through Multimedia CAL Programs

In this study, a set of multimedia CAL programs (simulations and video clips) from a CD-ROM (Tao, Mak & Lee, 1998) was used as a mediator for knowledge construction. Such types of programs are well suited for the purpose. Simulations allow students to freely experience, explore and manipulate the microworld by changing the parameters and visualizing immediately the consequences of their actions. Using the programs, students can formulate and test their hypotheses and reconcile any discrepancy between their ideas and the observation in the microworld (Papert, 1980; Bliss & Ogborn, 1989). The video clips in the CD-ROM are on physics phenomena and processes which offer focal points for discussion and reflection. They were designed to engage students in learning tasks, by asking them to consider some accompanying questions before looking up the answer/explanations in the program.

Computer Supported Collaborative Learning (CSCL)

Computer supported collaborative learning (CSCL) is a rapidly emerging field of study which started in the late 1980s. So far, there have been three international conferences (in 1991, 1995 and 1999), three special issues of journals (Koschmann, 1992, 1994; Steeples & Mayes, 1998), three books (Crook, 1994; O'Malley, 1995; Koschmann, 1996), and a sizable body of research on CSCL. CSCL is concerned with the question of how computer technology may support collaborative learning. According to Koschmann (1994, 1996), CSCL may be categorized according to (a) the locus of use, i.e., whether it is arranged within or across classrooms, or between classrooms and outside world; (b) how the use is coordinated in time, i.e., whether peer interactions take place synchronously or asynchronously; and (c) the intended instructional role, i.e., whether the technology is used for presenting/simulating a problem or for mediating communications. As such, CSCL can encompass a wide range of studies. In the past few years, due to rapid technological development, many CSCL studies have explored on-line collaboration on the internet and other means that adopt the latest technologies. The emphasis of these studies appear to be more on technology and its potential for learning than on whether and how it fosters learning. Whilst such studies are all worthy pursuits, CSCL studies in the naturalistic setting of the classroom, which is still the dominant place for formal science learning, appear to have been neglected. The present study is a contribution to this gap.

On a broader front, whilst there is widespread belief that the computer holds great promise for science education, studies on the use of computer in science classrooms have not yet yielded empirical evidence in support of such belief (Plomp & Voogt, 1995). From an analysis of 50 peer-reviewed journal articles on research on computer-based science learning published over the period 1988-95, Weller (1996) concludes that our knowledge about the impact of computers on science learning is still of a preliminary nature. He is critical that many of the studies examined a small number of variables, employed short-term interventions and pitted instructional delivery media, rather than instructional methods, against one another. Weller calls for more longer term studies that examine more variables and use fine-grained qualitative data collection and analysis to yield rich information and provide insights on computer-based science learning. In the past few years, there have been studies that adopted such an approach, for example, Reiner, Pea & Shulman (1995), Roth, Woszczyna & Smith (1996), White and Frederiksen (1998), Tao and Gunstone (1999), and McRobbie and Thomas (in press). Such studies have contributed much towards our understanding of the use of computers in the science classroom, but they are few in number.

Research Questions

The present study examines the process of peer collaboration during a CSCL physics instruction to investigate whether and how the instruction helps students to develop understanding of real image formation by convex lenses. Using Koschman's (1994, 1996) categorization, it is a CSCL study that investigates synchronous peer interactions in the naturalistic setting of the classroom using multimedia CAL programs as a means for presenting/simulating a problem. The research questions of the study are:

1. How are students' understandings of image formation by lenses facilitated by the multimedia CAL programs?
2. How do students, working in small groups, develop conceptual understanding of image formation?

Besides shedding light on how students develop understanding during collaboration the study also has practical applications that can inform instructional practices.

Methods

The multimedia CAL programs

The instruction designed utilized the following simulations and video clips from a CD-ROM (Tao, Mak & Lee, 1999). Brief descriptions of these multimedia CAL programs can be found in the appendix.

Simulations
1. Refraction by a convex lens
2. Images formed by a convex lens
3. Seeing an image formed by a convex lens
4. Measuring focal length of a convex lens

Video clips
1. Image formed by a convex and a concave lens
2. Locating image formed by a convex lens

In the simulation programs, the construction rules are not used in the ray diagrams. Instead, one or two cones of rays emanate from the object and these are shown to converge to a real image point, or appear to diverge from a virtual image point, after passing through the convex lens. This is intended to show the one-to-one correspondence between object and image points.

The video clips are each accompanied by a voice commentary that poses questions on the physics phenomena or situations shown, but does not provide any answer directly. After students have considered these questions they can click a button to see the answers/explanations.

Eliciting Students' Understanding of Image Formation

A test consisting of four questions was designed to elicit students' understanding of real image formation by convex lens (Figure 2). The test was administered prior to and after the instruction. The pre-test was preceded by a short teacher demonstration – the projection of the sharp image of a candle by a convex lens on a translucent screen.

Question 1 is intended to find out about students' conceptualization of image formation. The other three questions aim at confirming such conceptualization. Students' holding the point-to-point mapping model would very likely answer these questions correctly as follows:

- the image on the screen becomes blurred when the screen position is changed (Q2);
- the image remains intact but becomes dimmer when half of the lens is blocked (Q3);
- the image can still be seen if the eye looks directly through the lens (Q4).

On the other hand, students holding alternative conceptions (holistic, pin-hole or others) would very likely answer the questions incorrectly as follows:

- the size of the image changes but not its clarity (Q2);
- only half of the image would be projected on the screen (Q3);
- the image could not be seen if the screen was removed (Q4).

Subjects

Basically a convenient sample, the subjects in the study were 36 students from a Secondary 4 (Grade 10) physics class in a Hong Kong school. For many years, the school's student intake had been average according to the Secondary School Places Allocation Scheme. With funding from the government's new IT initiative, the school was one of the first batch of schools which had completed the construction of a well-equipped multimedia room. The multimedia room was used for the first time for the study.

The students had completed their study of optics in the previous year (Secondary 3). For the instruction, students were randomly assigned to work in dyads on the various tasks and their within-dyad interactions were audio-recorded. As far as possible, students of opposite sex were randomly assigned to each dyad so that their voices could readily be differentiated in the audio-tapes.

The Instruction

The instruction was carried out as follows. Throughout the instruction the students worked in dyads.

1. The teacher performed a short demonstration and administered the pre-test.
2. After the test, the teacher told students that they were to work on several simulation programs and video clips in a CD-ROM which might provide answers/explanations to the questions in the pre-test that conflicted with their own.
3. Following a worksheet, students worked through the assigned simulation programs and video clips in a sequence that directed their attention to the questions in the pre-test.
4. Finally, students were asked in the post-test if they had changed their answers/explanations to its questions.

The instruction lasted two hours (three 40-minute lessons). While students worked on the tests and CAL programs, the teacher and the researcher circulated amongst them to answer questions and to render assistance when needed. In general, students showed keen interest in the CD-ROM programs and there were few off-task activities.

Interviews

Three months after the instruction, students from 7 dyads were selected for individual interviews by the researcher's assistant. The 7 dyads included the 2 dyads who showed rudiments of the point-to-point mapping model at the pre-test, one dyad who changed from holistic to point-to-point mapping model, and 4 dyads randomly selected (see test results in the next section). During the interview, students were asked (i) about their understanding of real image formation by a convex lens (basically questions 1, 2 and 3 in the pre/post-test); (ii) whether and what they had learned from the instruction; and (iii) their views on the CAL programs and collaborative learning.

Data Sources and Analysis

The following data were collected for the study.

1. Transcripts of students' within-dyad interactions

Transcripts of students' within-dyad interactions recorded throughout the instruction formed the major source of data. The students encountered collaborative learning in an extensive way for the first time in this study and the amount of conversational data collected ranged widely among the dyads. In general, there was much discussion recorded during the pre-test, less during the post-test and very little during the CD-ROM activity. Five dyads were rather reticent and the data collected on them were insufficient for analysis. The interactions of two dyads were not transcribed since it was difficult to differentiate between the two male voices in the audio-tapes.

2. Students' written responses in the pre- and post-test

Students' written responses in the pre- and post-test were used to determine students' conceptualization of image formation before and after the instruction and these were triangulated with the data from the peer interactions. This was especially necessary for dyads whose written responses were brief or incomplete.

3. Transcripts of student interviews

Students' interviews were transcribed and analyzed for their conceptualization of image formation and also their views on the CAL programs and collaborative learning.

The study adopted an interpretive approach to data analysis. In particular, instances of conflicts and co-construction were identified from students' within-dyad interactions and inferences were made as to how these (and/or other modes of engagements) led to the development of shared understanding and knowledge construction.

Results

Students' Conceptualization of Image Formation at Pre-test

Table 1 gives the categories of students' answers in the pre-test. For question 1, only 2 out of 18 dyads showed rudiments of the point-to-point mapping model (dyads 13 and 17). These dyads drew ray diagrams of a cone of rays emanating from the candle flame and converging to a corresponding point on the image after passing through the lens. They did not, however, explicitly state the one-to-one correspondence between image and object points.

A total of 8 dyads showed the holistic model. This came as a surprise to the teacher who claimed that there was nothing close to such model covered in the textbook or mentioned during class. Of the remainder, 3 dyads drew standard ray diagrams using the construction rules without giving much explanation, 4 dyads treated the lens as a pin-hole, and one dyad's response could not be classified. These results generally corroborated those in the studies mentioned earlier.

For the other questions, only about half of the dyads were correct. In general, the 8 dyads who showed the holistic model answered the questions as expected, i.e., the image size changes but not clarity for Q2; only half of the image is projected on the screen for Q3; and without the screen the image cannot be seen for Q4.

Whilst 6 of the 8 dyads gave written answers/explanations to Q2, two dyads additionally applied the holistic model to draw two ray diagrams to show the change in size of the image with screen position.

Students' Performance at Post-test

Table 2 gives the changes in categories of answers from pre- to post-test. It can be seen that the point-to-point mapping model still proved to be very difficult. Of the two dyads who showed this model in the pre-test, one dyad (dyad 13) sustained it at the post-test, whilst the other (dyad 17) changed to the construction rules. Only one of the 8 dyads holding the holistic model changed to the point-to-point mapping model (dyad 14); the other dyads either retained the holistic model or changed to other scientifically incorrect conceptualizations.

On the other hand, there was substantial improvement in the answers/explanations given to questions 2 to 4. This is shown in Table 2 by the increase in the number of dyads giving correct answers from pre- to post-test and the concomitant decrease in the number of dyads giving wrong answers. The improvement is also shown in Table 3 which compares the number of dyads giving correct answers and explanations to questions 2 to 4 in the pre- and post-test.

Students' Conceptualization of Image Formation at the Interview

The interviews, conducted for 7 dyads three months after the instruction, gave each student an opportunity to articulate his/her understanding of image formation in much better ways than in the pre-/post-test. Table 4 gives the categories of students' responses. The point-to-point mapping model again proved to be difficult. The 5 students who explained image formation using this model came from one student each in dyads 6, 14 and 17 and both students in dyad 13. In the following, the students in a dyad are referred to as A and B, and student A of dyad 6, for example, is referred to as student 6A.

Although dyad 6 used the holistic model in both the pre- and post-test, at the interview student 6B showed not only understanding of the point-to-point mapping but also awareness of her conceptual change. Aided by rays diagrams, she claimed that she first used the holistic model in the pre-test ("The light rays travel like this and are converged here.") but later changed to the point-to-point mapping model ("The light rays are emitted here, divergent, then pass thru' the lens. Then the lens converges them and this [image] results."). Student 6B was not only articulate about her conceptualization of image formation but also showed metacognitive awareness of her learning. On the other hand, student 6A could not explain image formation claiming that he had forgotten about it.

Both students in dyad 13 who showed rudiments of the point-to-point mapping model at the pre- and post-test gave a very articulate explanation of the model at the interview. In particular, student 13B explained: “Light from the top of the candle goes downward after passing thru’ the lens. Then [light from] the bottom of the candle is converged to the top of the screen after passing thru’ the lens.” Later, towards the end of the interview, he reiterated: “I think … the image, no, light rays from [every point] on the object reach the corresponding position on the image.”

Dyad 14 was the only dyad who changed from holistic to point-to-point mapping model. At the interview, student 14A gave a very articulate explanation of the model whilst student 14B claimed that she could not recall any explanation of image formation. More details on this dyad will be given in the case study in the next section.

Dyad 17 showed rudiments of the point-to-point mapping model at the pre-test but changed to the construction rules at the post-test. At the interview, student 17A still used the construction rules but student 17B demonstrated understanding of the point-to-point mapping model. When queried, student 17B claimed that he changed to the construction rules due to his pragmatic approach to learning: “But the questions in the textbook and exams are all like this, only including three rays [the construction rules].” It may be that the other dyads who used the construction rules could have also been driven by such pragmatism.

As for questions 2 (move screen) and 3 (cover lens), 13 out of the 14 students interviewed gave correct answers/explanations.

Considering that students’ earlier study of optics in Secondary 3 (Grade 9) had resulted in rather poor understanding and that there was a time lag of three months between the instruction and the interviews, it is argued that students’ understandings as revealed by the interviews were generally quite remarkable.

Development of Understanding – a Case Study

Students’ within-dyad interactions provided rich qualitative data for understanding the process of peer collaboration as mediated by the CAL programs, enabling inferences to be made on how students developed understanding, or otherwise, of image formation. This is well illustrated by the case study of dyad 14. The students in this dyad engaged intensively in the tasks and with each other. At the pre-test, they gave wrong answers/explanations to all four questions but subsequently developed a good understanding of image formation.

A. Pre-test

At the pre-test, the two students co-constructed the holistic model for question 1 (image formation). At first, student A explained that the lens blocked the parallel rays to form an image, and student B pointed out that the lens converged the rays to a point (“As there is a lens blocking the rays and the lens is curved, the rays are converged to a point.”) They recalled that the image should be inverted. A explained that the rays were in “opposite directions” after converging to a point and B complemented by saying that the order of the rays was reversed (“No, the rays … the order of the rays is reversed when they’re converged. It’s because when the lens refracts the rays, the order is reversed. So an inverted image is formed.”) They then went on to draw the ray diagram of the holistic model. Throughout the discussion, the two students complemented and built on each other's idea to arrive at an explanation of image formation, albeit a scientifically incorrect one.

In question 2 (move screen), at first B suggested that when the position of the screen changed the image would become "bigger or smaller". When queried, B said: "It's smaller when [the screen is moved] further away, bigger when closer." A disagreed saying that moving the screen would change the clarity of the image. B countered by saying that this depended on the distance of the screen from the lens ("It's unclear when the screen is beyond certain distance."). When B was about to write down her answer, A queried B again: "Not the clarity but the size?" B argued that the question stated that the screen was moved *slightly* closer to or further away from the lens and this would not affect the clarity of the image. A countered: "No matter whether it's moved closer or further away, it's blurred because … (indistinct)". B maintained that "the image becomes blurred only when the screen is beyond the focus". At this point, A appeared to be convinced and subsequently B wrote down her answer. This is a case of conflict that eventually led to an agreement to a wrong answer/explanation.

In question 3 (cover lens), the two students co-constructed a wrong answer/explanation, that only half of the image was projected on the screen. At first, B suggested that the shape of the image would change. After several exchanges B said: "May be only half of the image remains". A agreed and went on to explain: "It's because half of it [the lens] is covered. At first there is a whole image".

There was no discussion recorded for question 4 (remove screen), probably because the dyad ran out of time. They wrote down a wrong answer: "We cannot see the image if the screen is removed."

Throughout the pre-test, the two students engaged intensively in the tasks and with each other, but they somehow co-constructed the holistic model and applied it to arrive at wrong answers/explanations to the other questions.

B. CD-ROM Activity

The two students again collaborated very well during the CD-ROM activity. Most of their exchanges were concerned with the running of the CAL programs and observing the results. They enjoyed the activity and highly commended the CAL programs spontaneously. For example, while working on a task in the worksheet, A remarked: "Luckily we have the computer. Otherwise, it'd be very difficult".

C. Post-test

At first, when asked by the teacher, the two students claimed that they had not changed their conceptualization of image formation subsequent to the CD-ROM activity. However, later when they revisited question 1 after finishing the other questions, they began to cast doubt on their ideas.

B: Is what's said earlier correct? Not necessarily parallel rays, not necessarily parallel rays. So we were wrong. Right? We can express it more simply.
A: Parallel rays? Not absolutely wrong.
B: What I mean is the rays are not necessarily parallel [to the principle axis].

B then drew a cone of rays from the top of the object (tip of the candle flame) which was converged by the lens to a point. This indicated that she had developed rudiments of the point-to-point mapping model. The researcher (R) who happened to be nearby asked them about rays from the bottom of the candle.

R: Very good. What about the bottom of the candle?
A: [Rays from] the bottom of the candle pass through the lens.
R: Draw these rays then.
A: But the problem is that I'm not sure if they pass through the upper or lower part of the lens.

A was puzzled and raised the query as to how the rays from the bottom of the candle should be drawn (" … not sure if they pass through the upper or lower part of the lens."). B then drew a cone of rays from the bottom of the candle to show to A.

B: Like this.
A: Very complicated.
B: But we understand now. No?
A: One parallel [ray], one sloping [ray].
B: No, ignore whether it's parallel or sloping. A point here and a point there. A point of the image and a point of the object. Totally two points. The ray passes through [the lens] and reaches the same [corresponding] point on the image. That's very simple.
A: Yes, that's right.

Still puzzled, A was thinking of using the construction rules to draw the ray diagram ("one parallel [ray], one sloping [ray]"), but B directed his attention at the one-to-one correspondence of the object and image points in the ray diagram that she (B) drew ("A point here and a point there. A point of the image and a point of the object. …"). A was convinced and accepted the explanation. The two students had developed the point-to-point mapping model of image formation through intensive engagement with the question (revisting the question, evaluating and reflecting on their previous answer/explanation, and presumably drawing on ideas from the simulation programs) and extensive exchanges with each other in which they confronted each other's ideas. The researcher played a mediating role by injecting an appropriate question at the right moment ("What about the bottom of the candle?") which helped the students to reinforce and further develop their emerging ideas.

The researcher also suggested the two students to run Simulation 4. After observing that the image was sharp in one position of the screen and blurred in other positions, the students revised their answer to question 2 (move screen) in the post-test script. They crossed out "Screen near lens, image magnified; screen further away from lens, image diminished", replacing it with: "The image is blurred since it is away from the focus [converging point of the rays]".

While the two students were working on question 3 (cover lens), the teacher (T) asked them why only half of the image was formed on the screen. A replied: "It's because there are fewer rays. Half of the rays disappear." The teacher then asked them which half of the image would disappear and A suddenly got the idea.

A: Oh. The rays go from here to there and there's still a point of convergence.
T: Yes. Yes. So this is different from what you thought before.
A: Only half of the rays are left.

Subsequently, the students wrote down in the test script: "The image becomes dimmer. This is because some of the rays are blocked and cannot pass through the lens to form the image."

When working on question 4 (remove screen), at first they maintained that the image could not be seen.

A: We can't see this … We can't see.
B: Yes, can't see the image … cos' there's nothing to receive the image, cos' there's nothing to receive the image.
A: Why can't we see the image? Just because there's nothing to receive the image?
B: No.
A: No. Now the image is replaced by the eye.

After some further discussion, they wrote in the test script: "Yes, because the eye receives light rays".

D. Interview

At the interview, three months after the instruction, A showed understanding of the point-to-point mapping model of image formation and gave correct answers/explanations to all the other questions. Not only was A articulate in his responses, he also showed awareness of his conceptual change by his frequent use of "at first, I thought … now I think …" in his responses. For example, in question 3 (cover lens):

> At first, I thought half of the image disappeared when half [of the lens] is covered. After the lesson, we knew that was wrong. The image is still there … it's dimmer. Half [of the lens] is covered … I thought the light can't pass thru' [the lens], but there are many light rays. They can pass thru' the rest [of the lens] and reach the other side.

This indicates that A showed metacognitive awareness of his learning.

On the other hand, when asked to explain image formation, B claimed that she could not recall it. The following exchanges with the interviewer (I) shows that B relied on recall and memorization:

B: I learned this last year. How can I remember?
I: No, you learned this three months ago [during the instruction].
B: I didn't know how to do even a month ago.
I: But you and your partner could do this after using the CD-ROM.
B: Really? Oh, I've forgotten about it.

However, B could give correct answers/explanations to the other questions, but she attributed this to recall from memory:

> Question 2 (move screen): They're [the light rays] converge to a point. They can't be converged when [the screen is] moved closer or further away."
> Question 3 (cover lens): Dimmer … because half is covered, the light can still pass thru' [the lens].

B's emphasis on recall from memory in her responses shows that she equated learning to memorization. Such an approach contrasted markedly with that of A.

This case study shows that the two students achieved understanding of image formation through intensive engagement with the tests and the CAL programs and with each other. There were many instances of co-constructions and conflicts identified in the peer interactions that led first to wrong answers/explanations in the pre-test but later to correct ones in the post-test. The case study brings out the importance of the mediating roles of the CAL programs and of the teacher/researcher. In particular, it shows that raising questions at appropriate times by the researcher/teacher helps students to evaluate and revise their prior conceptions.

Other Dyads' Development of Understanding

Dyad 14's collaboration and performance were exemplary of the intentions of the study. While other dyads were less successful they did show, in varying degrees, development of understanding of image formation as mediated by the CAL programs and by the researcher/teacher.

For example, dyad 4 showed an interesting development in their answer/explanation to question 2 (move screen) in three stages:

1. At first, after some discussion, the students wrote down: "screen closer – magnified image; screen further away – diminished image." They appeared to have based this on book knowledge, as student A recalled "The image is erect and magnified when [the object is] closer [than the focal length]. When further away [than the focal length], the image is inverted and diminished."
2. After finishing the other questions, the students revisited question 2. They changed their mind and applied the holistic model and revised the written answer as: "Screen closer, diminished image; screen further away, magnified image." Student B explained: "Because the rays need to travel further … the rays are sloping as they need to travel further, so [the image of] the candle is longer." They shifted from recalling (incorrectly) from the textbook to reasoning based on the holistic model.
3. Later towards the end of the pre-test, when the students revisited the question again, they developed some vague idea that the image might be blurred. Student A explained: "When [the screen is] closer, the image is behind the screen, so we can't see the image." However, they did not have time to pursue this further or rewrite their answer. It was after running Simulation 4 that they concluded that the image became blurred when the screen was moved to other positions.

Mediation by CAL programs.

As shown above, the CAL programs helped dyads 4 and 14 to revise the answers/explanations they gave in the pre-test. There were many other examples that illustrated the mediating role of the CAL program. Dyad 1 was a good example. This dyad showed the holistic model in question 1 which they applied to answer question 2, as shown by the following exchanges.

A: Draw two diagrams, one for the screen closer and the other for the screen further away.
B: Is it magnified?
A: [The image is] bigger when [the screen is] further away and smaller when closer.
(The students draw the two ray diagrams using the holistic model.)
B: Both are magnified?
A: No, this one is diminished.
B: Diminished?
A: It's diminished when [the screen is] closer.

The two students applied the holistic model to show how the image size changed with the screen position; there was no mention of the change in clarity of the image. Later when the two students were working on Simulation 4 the following exchanges were recorded. The students were changing the position of the screen in the program to investigate the effects on the image.

A: No change. There's no change, … Oh no, is it dimmer?
B: But it's [the lens is] not covered. Clearer or not?
A: No, it's clear only when it's placed exactly at the focal length [plane].
B: Exactly at the focal length [plane]?
A: Like this. Now it's [the screen is] dragged exactly to the focal length [plane] and it's [the image is] clear. But if it's here, the image is not clear.

Student A initially thought that the image was dimmer but student B pointed out that it was not a case of covering the lens (as in question 3) and suggested that they considered the clarity of the image. They found from the simulation that the image was sharp when the screen was placed at the focal plane of the lens and was blurred when in other positions. Following this, the dyad wrote in the post-test script: "Blurred image. The light can't be converged to a point, it's dispersed."

Students' Within-dyad Interactions

When the within-dyad interactions resulted in rich data, instances of co-construction and conflict were common and led to improvement in the students' conceptualization of image formation from pre- to post-test. The students' engagements were intensive with each making public his/her ideas and contributing towards the shared understandings. Students provided mutual support in the form of suggesting further or alternative ideas, raising queries, seeking clarifications, etc., and this appeared to be essential for them to move on in the steps towards the answer/explanation. This enabled students to think more deeply about the question and to invoke different ideas to work on the questions. Conflicts arose when students disagreed on the ideas proposed, but in all instances students eventually came to an agreement and co-constructed an answer/explanation after some discussion.

However, co-construction could lead to correct as well as wrong answers/explanations to the questions. The case study and other data quoted above showed that students' ability to co-construct correct answers/explanations appeared to depend on an interplay of several factors which included:

(a) the prior ideas that the students brought to bear on the questions;
(b) how students interacted with each other and the ideas they invoked in the process; and
(c) the mediation by the CAL programs and the teacher/researcher, if any, that might help students to consider or generate alternative ideas.

It should be noted that not all the dyads collaborated well during the instruction. Five dyads were rather reticent and the conversation recorded was limited only to procedural matters such as reading out the questions and working out how to run the CAL programs. There was very little discussion on the questions per se. In general, these dyads showed poor understanding of image formation and had little or no improvement from pre- to post-test.

Different Approaches to Learning

The data also reveal students' different approaches to learning. Some students relied heavily on recall and memorization. When attempting the questions in the pre-test, these students searched their textbook for answers rather than thinking them out. For example, in answering question 4 (remove screen), dyad 4 searched the textbook and simply wrote down "page 51" as the answer without elaboration and discussion. In question 2 (move screen), many students misread the question and took moving the screen as moving the object. Apparently, these students had learned by heart from textbook the nature and position of the images formed by convex lens for different object positions, and they recalled this as they read the question. Some dyads managed to discover such misinterpretation after some exchanges, but others went on to give a wrong answer/explanation. At the interview, students 6A and 14B (see case study of dyad 14 above) could not explain image formation claiming that they had forgotten about the answer. Students like these who adopted an approach based on recall failed to develop or sustain understanding of image formation. On the other hand, as shown earlier, their partners, students 6B and 14A, showed not only understanding of the point-to-point mapping of image formation but they were also aware of their conceptual change. Students adopting such a metacognitive approach to learning developed a comprehensive understanding of image formation.

Students' Views on CAL programs

The interview data showed that 11 out of the 14 students interviewed were positive, in varying degrees, about the CAL programs. In particular, students who developed a good understanding of image formation were very articulate in their comments on the programs, as the following excerpts show:

> I can experience something myself and don't just listen [to the teacher]. How do the rays go? After I think of something, I can test if it's correct. Then I learn something myself. (Student 14A)

> You can try it yourself, how the light rays travel and don't have to refer to the drawing of the teacher. I can understand more. I can try it out in details and remember more clearly. (Student 17A)

Students who showed little or no improvement in their understanding were much less articulate about the advantages of the CAL programs. For example, several students simply said "it's less boring."

When asked about what they had learned, again those who achieved understanding were very articulate.

> Yes, for example, there is something that can be moved. When you move the object, it [the program] will show you the image. Then I can learn it. It's because earlier I had to memorize, for example, how the parallel incident rays are refracted [by the lens] to the focus. Your impression is deepened after using the CD-ROM and you don't have to memorize it. You know approximately the size and position of the image. (Student 13A)

Several students admitted that the CAL programs had helped them to understand image formation, but they claimed that they had not learned much from the CSCL instruction "because it was similar to what the teacher taught previously." These students equated learning to the acquisition of factual knowledge and did not regard understanding as an important aspect of learning.

Students' Views on Collaborative learning

Of the 14 students interviewed, 9 were positive about collaborative learning. Again those who performed well were very articulate about its advantages, as shown by the following excerpts:

> We can help each other out. … I learn to think in more ways, not only relying on mine. During the discussion, we can talk about it when we don't know how to do it. (Student 1B)

> We can exchange ideas … when working together, we can come up with more things [ideas]. No disadvantages. (Student 7B)

Students who were negative about collaborative learning gave reasons such as “it led to conflicts”; “I felt not very natural cos’ I’m not familiar with him.”; and “The classmate didn’t speak up and I had to do it all by myself.” Given that the class had not adopted collaborative learning in an extensive way before, such views were not unexpected.

Summary of Findings

Although the study was not based on a treatment-control group design, it can be argued that the CSCL instruction was generally effective. This is substantiated by the following:

(a) many students showed improvement in performance from pre- to post-test (they failed to develop understanding of image formation in their earlier study in Secondary 3 [Grade 9]);
(b) most students engaged intensively in the tests and CAL programs and with each other during instruction;
(c) many students sustained their understanding of image formation when interviewed three months after the instruction.

The findings pertaining to how CSCL helps students in developing understanding of image formation are summarized below. These findings are presented as assertions rather than as generalizations since the sample size is small and cannot be claimed to be representative.

1. Collaborative learning provides students with experiences of conflict and co-construction that are conducive to the development of understanding.
2. Conflicts and co-construction can foster students’ intensive engagement with tasks and with each other. Conflicts usually lead to co-construction when students subsequently comes to agreement.
3. CAL programs can play a mediating role in developing students’ understanding.
4. The teacher can play a mediating role that helps students to invoke or generate ideas in developing understanding.
5. Co-construction can lead to scientifically correct as well as incorrect understanding. Students’ development of correct understanding depends not only on their prior ideas but also on (a) their interactions and the ideas they invoke, and (b) the mediation by the CAL programs and the teacher.
6. Students adopting an active and metacognitive approach to learning are more likely to develop and sustain their understanding.

Discussion

CSCL is a useful and suitable way of organizing computer-based science learning in the classroom. The present study has shown that CSCL is particularly helpful to students who are comfortable with peer collaboration and are prepared to engage intensively in the learning tasks and with each other and to try out and test their ideas on the multimedia CAL programs. Following the CSCL instruction sustained learning in individual students has taken place. This is consistent with the study’s Vygotskian perspective of learning. The study thus goes some way to answering the criticism that technology is often introduced into the classroom without a theoretical and research basis that informs instructional practices, and supports Salomon and Almog’s (1998) argument that a sound theoretical basis is necessary if the technology is to have productive use. Salomon and Almog further suggest that “a major justification for the employment of computers is the acceptance of constructivist conceptions and the growing understanding of learning as a social process" (p.222) — these are two specific features of the present study.

According to the Vygotskian perspective, peer interactions are central to the development of knowledge and understanding on the intermental plane. The study found instances of conflicts and co-construction in the peer interactions that served to engage students intensively in the learning tasks and with each other and inference was made that these were conducive to the development of understanding. This finding is consistent with those of two earlier studies: Tao and Gunstone (1999) on CSCL's role in conceptual change in "force and motion", and Tao (1999) on how students' success in physics problem solving depends not so much on their ability but on how they interact and whether they invoke the relevant physics principles and strategies.

CSCL provides an environment that can engage student in learning, but it does put the onus on the students themselves. In computer-based learning, all too often students simply browse through multimedia CAL programs and explore the special features without giving much thought to the underlying concepts and principles and this will not lead to substantial learning (Lawless & Brown, 1997). In the present study, students who took an active approach, gave careful thoughts to the learning tasks and interacted intensively with their partners developed understanding of image formation.

Students' conception and approach to learning are also crucial. If students adopt a passive approach relying on direct transmission of knowledge from teacher and recall of factual information, as was the case with some students in the present study, no sustained learning will result. On the other hand, the students who developed a comprehensive understanding of image formation in the study were reflective and showed metacognitive awareness of their learning and conceptual change subsequent to the CSCL instruction. The development of metacognition has long been seen as important in science instruction (Baird et al., 1991).

The research reported in this article was supported by an award of the CRCG Research Grant of the University of Hong Kong (10202619/13924/10100/323/01).

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Appendix: Multimedia CAL Programs Used in the Study

Simulations

1. *Refraction by a Convex Lens.* This shows the ray diagram of a ray-box directing (a) a cone of rays (divergent flux of light), (b) parallel rays, or (c) a single ray at a convex lens (Figure 3). Students can change the position of the ray-box and the point of incidence of the rays on the lens.

2. *Images Formed by a Convex Lens.* This shows the ray diagram of a cone of rays from a point on an object refracted by a convex lens to form a *real* or a *virtual* image point. Students can (a) drag the object to different positions, on as well as above and below the principal axis, (b) change the divergence of the cone of rays, and (c) change the point of incidence of the light rays on the lens.

3. *Seeing an Image Formed by a Convex Lens.* This shows, in stages, how the eye sees a real or a virtual image formed by a convex lens. In either case, a cone of rays from the top of an object is refracted by the convex lens to enter the eye to produce vision. Students can change to two cones of rays, one from the top of the object and the other from the bottom. They can also drag the eye to different positions.

4. *Measuring Focal Length of a Convex Lens.* This shows the experimental set-up of a convex lens projecting the image of a distant object on a screen. Students can drag the screen to different distances from the lens and observe how this affects the clarity of the image on the screen. An accompanying ray diagram shows two parallel rays from the distant object converged to an image point on the focal plane. The screen is also shown in the ray diagram. The image is sharp only when the screen is placed at the focal plane.

Video clips

1. *Images Formed by a Convex and a Concave Lens.* This shows (a) a convex lens and (b) a concave lens being moved slowly away from a small toy (the object). The size and inversion of the image are shown to change as the object distance is gradually increased.

2. *Locating Image Formed by a Convex Lens.* This shows a translucent screen being used to capture the sharp image of a lamp formed by a convex lens on it. It shows that the image becomes blurred if the screen is then moved slightly closer to or further away from the lens. The screen is also shifted sideways so that it captures only half of the image, leaving the other half in mid-air.

Table 1

Categories of Dyads' Answers in Pre-test

Q1 (image formation)		Q2 (move screen)		Q3 (cover lens)		Q4 (remove screen)	
Point-to-point mapping*	2	Blurred image*	8	Intact/dimmer image*	11	Light enters eye*	9
Holistic	8	Change size	7	Image halved	5	No image	2
Construction rules	3	Change nature	3	Others	2	Others	7
Pin-hole	4						
Others	1						

Total number of dyads = 18

*Correct answers

Table 2

Dyads' Changes in Categories of Answers from Pre- to Post-test

Q1 (image formation)		Q2 (move screen)		Q3 (cover lens)		Q4 (remove screen)	
Point-to-point*	2 → 2^	Blurred image*	8 → 13	Intact/dimmer image*	11 → 15	Light enters eye*	9 → 10
Holistic	8 → 4	Change size	7 → 1	Image halved	5 → 1	No image	2 → 1
Construction Rules	3 → 7	Change nature	3 → 4	Others	2 → 2	Others	7 → 7
Pin-hole	4 → 2						
Others	1 → 3						

Total number of dyads = 18

* correct answers

^ means 2 dyads gave such answer in pre-test, 2 dyad gave such answers in post-test

Table 3

Correct Answers, Explanations of Dyads in Questions 2, 3 and 4 in Pre- and Post-test

	Q2	Q3	Q4	Total number of correct answers	Total number of correct explanations
Pre-test	6, 2^	12, 8	10, 7	28	17
Post-test	12, 5	15, 11	14, 8	41	24

Total number of dyads = 18

Maximum number of correct answers/explanations = 18 dyads x 3 = 54

^ means 6 dyads gave correct answers, 2 dyads gave correct explanations to Q2 at the pre-test.

Table 4

Categories of individual students' responses at Interviews

Q1 (image formation)		Q2 (move screen)		Q3 (cover lens)	
Point-to-point mapping*	5	Blurred image*	13	Intact/dimmer image*	13
Holistic	2	Change size	1	Blurred image	1
Construction rules	5				
Pin-hole	0				
"Forgotten"	2				

Total number of students interviewed = 14 (from 7 dyads)

*Correct answers

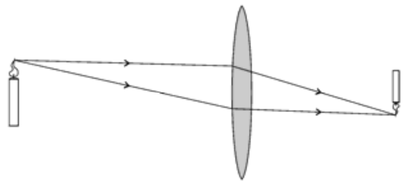
Figure captions

Figure 1 (a) Point-to-point mapping model
(b) Construction rules
(c) Holistic model
(d) “Pin-hole” model

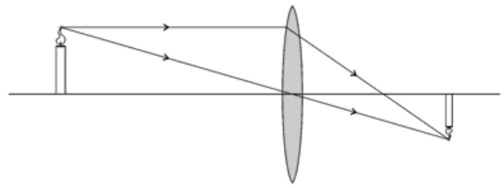
Physicists’ conceptualization of image formation (a) and students’ alternative conceptions (b), (c) and (d)

Figure 2 Questions in the pre- and post-test

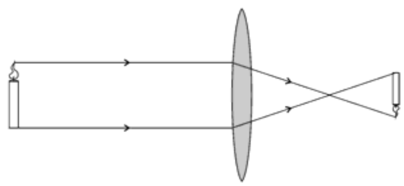
Figure 3 Sample simulation program: Refraction by a convex lens



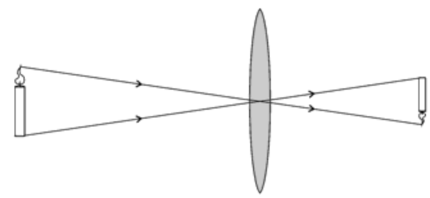
(a) Point-to-point mapping model



(b) Construction rules



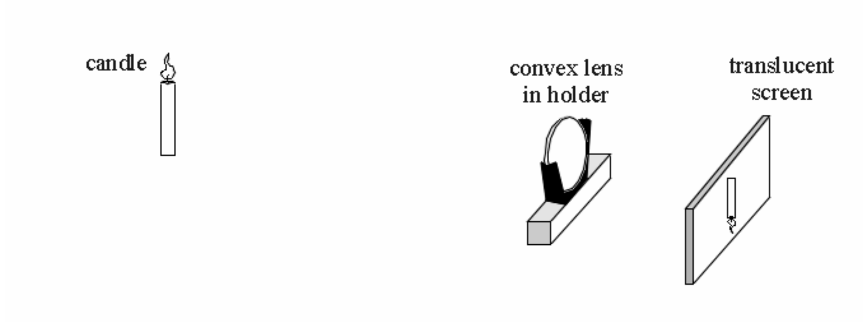
(c) Holistic model



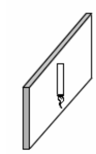
(d) “Pin-hole” model

Figure 1. Physicists’ conceptualisation of image formation (a) and students’ alternative conceptions (b), (c) and (d)

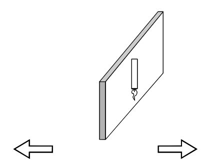
Your teacher will use a convex lens to project an image of a candle on a screen.
Working together *in pairs* answer the following questions about the image formed.



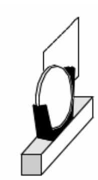
Q1 Explain *in your own words* why the lens forms an image on the screen. If necessary, illustrate your explanation with a ray diagram.



Q2 What will happen to the image if the screen is moved slightly (i) closer to and (ii) further away from the convex lens? Explain.



Q3 What will happen to the image on the screen if half of the convex lens is covered with a piece of card? Explain.



Q4 Can we see the image if the screen is removed? Explain your answer.

Figure 2. Questions in the pre- and post-test

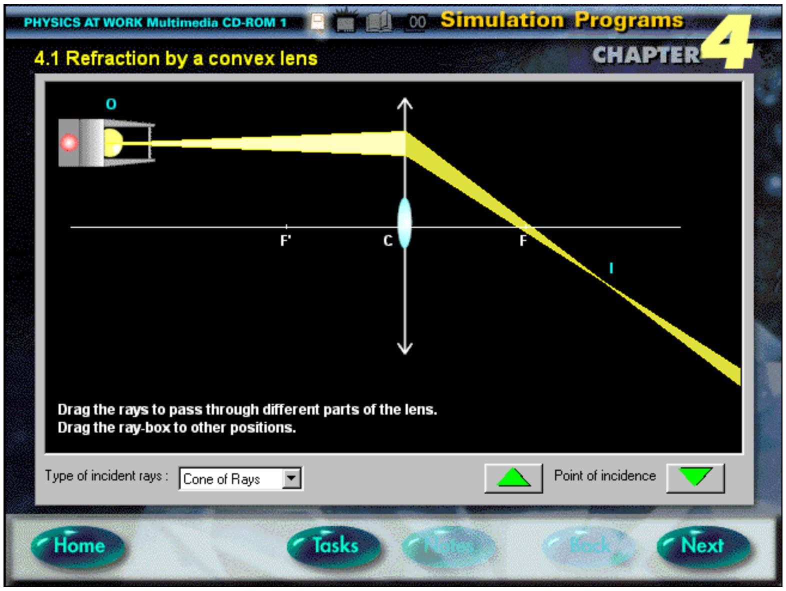


Figure 3. Sample simulation program: Refraction by a convex lens