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## **Playing with Light**

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**ABSTRACT** The authors conducted action research by developing workshops that involved teacher-participants in their own exploratory learning. The authors facilitated participants in researching of what they noticed, and wanted to understand about light and shadows by structuring the environment, and the questions that were asked of them, in ways that integrated practices of teaching into those of researching. During the workshops, transitions evolved in how participants used materials to make light and dark effects and interacted with each other. Transactions also occurred in how the authors intervened to teach and research what participants did, and to encourage their reflective observations. It is proposed that such explorations offer new beginnings for extending understandings of physical phenomena and of the world, as made through our actions and thoughts.

## **Introduction**

Each day is divided into light and dark. Each division contains something of the other: within the light are the darknesses of shadows; within the dark there is usually a glow from something lit - or even the stars. Each day as we casually go between light and dark many times, the changes seem familiar. We seldom stop to look at the appearances of light and shadows, or to wonder about what we see.

How might a teacher elicit learners' interest in something so ordinary that we pass it by, but which contains so much to notice and think about? This is a question that comes from a teacher's concerns that the curiosity each student has for nature might make beginnings for what each learns. We are teachers who hoped that through involving learners in exploring something physical, their curiosity would deepen into questions of their own. Doing this, we believe, is a teaching of physics of looking more closely into the continual interplay of light and dark in the environment around us.

However, to teach by involving students, in forming their own explorations of light and dark, was something new for us and for most other teachers of physics. It would mean changing our own relationship to the subject of light and dark, so that we could see it through the behaviour presented in the phenomena and not only through how we had been told to interpret it by formal instruction. For school students to have this sort of experience as learning, their teachers would have

to go through it too. So we realised that within what we hoped to try, we would have to consider changes in how we, teachers, and students interact with each other, and experience light and dark.

To imagine the possibilities for our teaching, we met together. Together we thought, played with shadows, planned and conducted explorations with other participants, and reflected on what happened.

This was a research process. And, since the research also changed us, our participants, and what each did and understood while we were together, it was a research through taking action and bringing about action.

Our research developed into the project of offering workshops for schoolteachers, through which they might actively explore light and dark. We conducted five workshops, with over 20 participants in each. Four workshops were presented through conferences for teachers; the fifth was one meeting of an academic course for pre-service teachers. One conference workshop met on two consecutive afternoons with the same group of teachers. The others were one-time meetings, two hours in length. Conference participants were in-service teachers from public and private schools in the urban areas of Boston, New York City, and Philadelphia. Most taught in primary schools; others taught in middle school, high school, or colleges of education. Our taped and written records of the workshops were sources for the discussions that follow.

Exploration brings with it tensions and doubts felt by all of us, teachers and learners. We were especially concerned about how the prior training of most teachers does not allow for learning through experiences that evolve as they work with materials. In "**High Stakes" Testing and the Promise of Mind in Action**" we describe the prevailing background under which testing determines most of the classroom curriculum in the USA, and the research tradition that supported us in reacting against that. '**Structuring an Environment for Exploratory Research Experience**' conveys how we acted from these concerns in how we shaped the workshop environment to invite their playfulness and in the sorts of questions we asked our participants.

What happened during these workshops was also a process of research and learning. In facilitating, we became aware of changes happening across the group that revealed the teachers' personal engagements with light and dark. We had already experienced these changes in a practice session held just for ourselves. As we encountered them again during the workshops, we felt these changes were developments that are integral to the process of doing exploratory research. We became intrigued by noticing the 'transitions' that signalled, for us, that these developments were coming about. In **Transitions Seen Afterwards**', we draw on episodes from the workshops to portray these transitions: in how materials were used; in interactions among participants; in participants' reflections on teaching and learning.

The specific details, of what the teachers did and talked about, came from what intrigued them about light and dark, and from how their thoughts about that were changing. These details contain the process of each teacher's own research and learning. In **The Shadows and Brightness Made by Tubes and Candles**', we include this aspect of research in the narrative of what two teachers did while exploring the lengths of shadows cast by candles.

Close-up stories such as these seldom get reported or even noticed by teachers, yet are evidence and analysis of how what we understand changes as we act with materials. So we hope that even this written text will be a form of action, a resource for teachers in interpreting and extending

their own experiences with learners. Along the way, we share the fascination of all there is to notice within the familiar effects of light and dark.

That is the wonder we hoped our project might bring into relief, as something everyone can question and explore.

### **'High Stakes' Testing and the Promise of Mind in Action**

Our workshops were an action research made in reaction to what we feel is lacking in school experiences for students. Since most of our workshop participants taught in the USA public schools, it was that context, in particular, that we hoped to challenge and extend. However, our own educations included attendance at public and private schools in the USA, England (Fiona) and Germany (Petra [1] and we had personally sensed this lack across most of these school settings. In working together, we were doctoral students learning the methodology of 'teaching/learning research', introduced by Eleanor Duckworth, our advisor and sponsor. We began to see how that research practice might enable us to act on concerns we shared about the prevalence of authoritarian methods in school science instruction, which leave no space for students to act with their minds (Hughes-McDonnell, 1996; Lucht, 2000). As we learned, it was part of a research tradition that stood in counterpoint to the excessive pressures, such as 'high stakes' testing, that constrain curriculum in the USA public schools.

The USA public schools, being funded from taxes, are a service extension of local government and are accountable to the public for their conduct and product. While many forms of measures are used to make schools accountable, those with the most visible impact are the test scores achieved by pupils taking standardised exams administered by the state or some other agency. Scores on multiple-choice exams often determine the academic standing of individuals, such as:

- placement in 'low track' classes where the expectations, curriculum and resources are minimal;
- promotion from one grade to the next;
- graduation from high school.

Test scores are also aggregated to make comparisons between classes, schools, school districts, states. These comparisons may be used competitively to set teachers' salaries or apportion funding among schools or school districts (Heubert & Hauser, 1999).

The lives and futures of individual students, their teachers and schools, are so profoundly affected by exam scores, that testing bears the weight of a 'high stakes' event for everyone involved (Heubert & Hauser, 1999). To help students out, teachers and schools devote considerable class time to test preparation. The test becomes what they do in schools, displacing other forms of studies (Madaus, 1988; Weiss & Fege, 1988; Kaufhold, 1998; Darling-Hammond, 1997). Test preparation includes: repetitious drills, review of test questions, and test-taking strategies such as picking out the 'distractor' items in a multiple choice question or doing old exams for practice. The students are there to become proficient at the test.

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Although test scores are taken as proof of individual merit and competence, they correlate with the examinees' economic and social status. Test-based tracking, ranking and college placement perpetuate those divisions (Lemann, 1999). Classes and schools where test-based curriculum dominates the most impoverishing the learners' overall curricular experience are those associated with lower 'tracks' and lower economic and social status (Madaus, 1988; Darling-Hammond, 1997; Heubert & Hauser, 1999). While policy makers and the public support the use of 'high stakes' tests as a lever to make schools accountable and make students perform (Phelps, 1998; Heubert & Hauser, 1999), some educators (Madaus, 1988; Perrone, 1991) and administrators (Weiss & Fege, 1988; Kaufhold, 1998) are critical of the resulting narrowness in curriculum and opportunities for learning.

Those most affected by testing - the students - go through this routine and are denied the opportunity to develop their own understandings of the subject under study. When they see a subject matter only through the simplified cut-out representations of textbooks and tests, they do not experience it as a whole, with interconnections among all its properties. The closed circularity or 'alignment' between instruction and testing leaves nothing unresolved; nothing that might draw students' interest and involvement.

The stakes of testing are too high; too high for students whose futures depend on a score, too high for teachers and principals whose careers and salaries are tied to those scores. However, even more is at stake in what students and their communities - lose under this practice. For the sake of a test 'measurement', so much has been given up: the personal development of students' minds. Such a loss, which we saw first-hand among our classmates, students and children, is too commonplace and tragic. Believing that all students can develop full understandings of their own, our work with teaching and learning came to differ from the methods usually promoted under testing.

For alongside this pressured conformity of public school curriculum, there have been alternative visions and practices of teaching. In decrying the sterile exercises of public schooling in the early twentieth century, the philosopher and educator John Dewey (1859-1952) expressed how the child's mind grows through play and work together. He argued for a school environment that encompasses activities having meaning in the child's everyday life. By doing 'gardening, cooking, sewing, printing

plays and games' as a 'whole' integrated experience, the child comes to knowledge that is more real, more complete, than that acquired by retracing prescribed routes to an end (Dewey, 1916, pp. 196-198). This activity, by connecting with the child's own resources of mind and body, would be a more vital preparation for participating in democracy, than schooling children by enforcing uniformity upon them.

Such thinking found its way into practice through the lab school founded by Dewey (Mayhew & Edwards, 1936), efforts to introduce activity with materials to school curriculum (Elementary Science Study (ESS), 1965, 1973), and the work of individual teachers (Hawkins 1997). These practices found a natural link with the contemporary Genevan research of Jean Piaget (1896-1980), Bärbel Inhelder (1913-1997) and other associates, in which the child's thinking is interactively investigated as it forms (Piaget, 1926). This work showed that, through being in action with real things and problems, the child 'constructs' understandings having integrity within what the child then knows and does, which become resources for further action and development. For example, coming to

understand the different appearances a pencil's shadow can have (from vertical line to circular dot) involves coordinating several points of view (from upright to edge-on; Piaget & Inhelder, 1948). This process involves a learner both in experimenting with objects and light, and in interpreting what is projected and seen. Understandings cannot be just externally imposed, for they are worked out through one's own initiation of activity and reflecting.

Eleanor Duckworth, a student of Piaget and contributor to an alternative science curriculum (ESS, 1973), realised a quality that intrinsically interwove through all these experiences with action, thought and children's development. While she was working to understand a child's thoughts by posing questions and new activities, she was at the same time supporting the child's own process of expressing, exploring and evolving new understandings. In the action of researching lay the stimulus for teaching and learning; and within the nature of the child's learning and her teaching, there arose the very development which was so intriguing to research, to try to understand better (Duckworth, 1986, 1991). Researching and teaching were inseparable actions; one coevolving process of change among all the participants, and their relationships with things of the world.

The method of teaching/learning research', that emerged through Duckworth's work (Duckworth, 2001), can be practiced by a school teacher with a class (Hughes-DcDonnell, 2000), or in other informal settings (such as our workshops). Their mutual involvement is sustained through doing something together with a material subject that excites learners' own interests. What they do, invent, discuss and come to understand, is the curriculum. The curriculum unfolds in the narrative of everyone's efforts and ideas with the subject. The following excerpt from a kindergarten class illustrates this:

*[One day] ... the teacher asked [the children] how they could make a shadow on the blackboard.*

*'We have to turn on all the lights.' They did.*

*'We have to have something.' They went to get a teddy bear, and one child placed it against the blackboard.*

*'You can't see anything, you can't see any shadow.'*

*'I know!' one child exclaimed, seizing the teddy bear and moving it slightly away from the blackboard. A small pale shadow was visible.*

*'Yeah, but you can't see what it is,' another child said.*

*What to do? She let them think about it... She gave them a flashlight and let them figure it out. They had a hard time getting themselves organised... the flashlight was too close to the teddy bear... the teddy bear was too close to the blackboard, and so on. Finally they succeeded.*

*'You can see the shadow, you can see the shadow!' 'It's funny, you can see the ears.' 'But you can't see its face.'*

*(Duckworth, 1990, pp. 49-50)*

In working out relationships among teddy bear and lights to produce a distinct shadow, the children learned and still had more to go on with such as casting the bear's face into shadowed profile.

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These developments in action and thought also occur when adults participate as learners. Then, the teacher's work is *not* to treat the adults 'as if they are children, but to involve them in activities that open up a subject matter so it genuinely intrigues *them*, to explore and understand. And, like light and dark, so much of the material world passes us by unexamined, that even what adults think they know formally, often comes undone when they explore it directly through their own actions.

Reforming understanding out of experience that addresses one's own questions, is a way of accessing what our minds can do a powerful tool to one's understanding of self, and of the learning trials of others. By contrast, the school task of 'aligning' curriculum to match testing requirements, leaves little opening for finding and using one's own mind in action - either by the teacher or the students. That constriction imposes starkly upon learners' personal sense of intellectual worth and world. We hope that those in schools can come to know the light and life of their minds, even from such small beginnings as looking closely at light and dark.

### **Structuring an Environment for Exploratory Research Experiences**

When we came together to prepare these workshops, we had to develop an understanding in common. That shared understanding would become the environment for our discussions together. It would also be a resource in preparing an environment for our workshop participants. It was something we had to form together; it was part of our learning as researchers.

From our separate work, there were already connections among us. Each of us had studied and taught science. For each of us, these prior experiences raised concerns about the human side of science and its teaching. We chose doctoral studies in education and sociology as a way to examine science critically, and in hopes that our research could bring about openness and change in science. Through our first interview studies of physics students (Hughes-McDonnell, 1996; Cavicchi, 1997; Lucht, 2001), we were beginning to analyse the social and pedagogical features that make physics so inaccessible to students.

Together, we wondered what experiences we might provide to learners as an alternative. We were intrigued by the possibilities of engaging learners with materials as an entry to physics that would be quite different from the usual symbolic explanations. This interest also connected with how we had been setting up situations for learners as we learned to practice Duckworth's method of teaching/learning research.

While discussing our concerns for preparing a learning experience, we realised it was not enough just to talk. We had to try something out with light and dark ourselves. This was more challenging than we expected. At first, it felt awkward: how would we start? In being together to do something with materials, we felt separately vulnerable and uncertain. We gradually found ourselves developing a feeling of trust in the materials; that what we did and saw with the materials could make beginnings for us and our ideas.

We were aware that a feeling of playing with the materials in our hands, eased this beginning. By reviewing together a videotape of our own activity, we were able to track this transition and how play enabled it.

We supposed that these uninhibiting qualities of play, might also appeal to the adult teachers attending our workshops. So we discussed how we might prepare the workshops to invite

their inclinations for play and spontaneity. Our thought was to encourage playfulness through how we structured the workshop environment. This environment included the workshop site and occasion, spatial arrangements within the room, materials and other physical resources, our spoken introductions, interactions and questions during the workshop, and the time allotted for doing each phase of the workshop. Below we describe the choices we developed to provide structure.

There was a further grounding for our sense that spontaneity in ideas and activities could extend the depth of learning. It connected with an emphasis on respecting and beginning from children's spontaneous ideas that arose through educational projects influenced by Piaget's work (Hsueh, 1997). Yet spontaneous qualities of learning are intrinsic to any research - whether in science or in qualitative studies. Something may happen - in the activity, phenomena or human interactions - that is unknown, new, puzzling or disturbing to the teacher-facilitator.

Conducting such a workshop demands, stretches, and can deepen, a teacher's spontaneity for working within ambiguity and uncertainty. While staying attentive to concerns that might involve physical safety, we sought to respond to our own uncertainties, about how something was going, without expecting that it come to a particular resolution.

### ***Making Structure Choices in Setting and Materials***

Our decisions that added structure to the setting and materials were prepared in advance, and spontaneously revised during each workshop. For example, we chose to hold our workshops in classrooms that could be darkened, instead of outdoors. With this choice of environment, we also scoped the 'content': the kinds of light and shadow effects that might be most accessible to notice. An outdoor environment might provoke interest in the sun-cast shadows of our bodies; by contrast, our indoor environments offered several light sources and ways of regulating them. During the workshops, participants could modify this as a group, by switching the room lights on or off, and individually, by using smaller lights, such as flashlights or candles.

Along with the light sources in it, this indoor environment had a structuring effect. It allowed participants to follow light's appearances and paths in darkness. They could observe what brightnesses and shadows came about as they rearranged the materials and lights. We also found the darkness itself made for a quiet and playful setting. It brought out the interest of just watching the lights and shadows. In the dark room, people quickly began cooperating, in holding and finding things, and in admiring what each other had done.

We chose to provide materials that came from everyday life. These materials, such as foil, crayons, combs and Christmas candles, were appealing in themselves. People's everyday associations with these materials often made a beginning for what they did. For example, one woman wrote directly on a light bulb with a magic marker and then wondered how her light-and-writing device compared to a Xerox copier. Another made V-shaped scissor cuts through multi-folded paper. This cutting activity recalled the craft of cut-out lamp shades often used at Christmas, where light passes through decorative openings and casts patterns around the darkened room.

Had we provided materials that are purposefully designed for pre-set experiments with light and shadow, such innovations might not have evolved. So both the commonplace materials and people's personal experiences with them integrally structured how they started. By way of those first engagements, what participants did began to evolve a structure of its own, coming out of what they

did, more than from what we initially prepared.

Teachers may find many ways, other than those we tried here, for supporting students' explorations with materials and a working environment. As teachers, we found ourselves continually questioning and rethinking our teaching decisions and how, by the structural features they entailed, learners might or might not respond with fascination with light's behaviour. Our observations suggested that participants' deepened research was often ignited by very specific features of workshop materials and structure, such as whether:

- extension cords could reach someone's worktable;
- the straws and cups we provided were transparent or opaque to light;
- a participant expressed curiosity or confusion about something another participant was trying.

We became aware of how these details were part of the structure each participant experienced. We thought about how, by changing these details (such as in rearranging cords and power strips, selecting paper or plastic ware, asking participants to talk to each other about what they tried), we might facilitate more of what was evolving for each of them.

Part of preparing to support exploration involved us in becoming open *not* to expect that everything would happen as we planned it. We tried to see the possibilities inherent in specific materials and interactions. In the specific observations that participants made such as seeing unexpected bright spots projected through an opening - we saw potential for them to realise something they were unsure about. Perhaps we could encourage them to use that as a beginning to check it out more, to really know for themselves. So, while our preparations involved planning, what happened in each workshop could not be planned and would entail our spontaneous responses. Once the activity was underway, participants' responses to what we had structured would change how each of them experienced it.

### ***Making Choices about Structure through Asking Questions***

Our interactions during workshops were our own exploratory efforts to support and question what participants were developing in their activities. We were learning what it was like to use our responses as part of the structure that supported them in exploring. This was an uncertain process in itself. Often we could not tell if something we said was productive in ways that mattered to what that person was thinking.

We started off each workshop with a prepared question. In composing it, we sought to evoke light, shadow and possibilities for doing something with those phenomena. We did not want to imply that we expected any certain kind of activity or answers' to result from involvement in our workshop. It was not our intention to guide participants toward a particular fact or principle about light. However, that did not mean we felt they could not work out and understand the behaviour of light through what they did. We believed they could. We trusted that their activities would engage them with light in ways that were meaningful for understanding more in what interested them.

We carried these concerns over into our spontaneous questions or interactions with individuals or groups as they explored light and shadow. Thus, we did not ask what they were doing or thinking in ways that suggested we regarded the understandings they were forming as 'answers'



reducible to 'right' or 'wrong'. What we did express, repeatedly, was our genuine intrigue with what they had gotten light to do, how they were thinking about that and what they wanted to try next.

For example, the participant who used a black magic marker to write letters on a light bulb noticed that, when she turned the light bulb on, it cast strange-looking shadows on the wall that did not read like the letters she had written. In trying to interpret them, she said the letters are not upside-down. They are mirror image'.

One of us asked 'How do you see the mirror image?' This was a question that is open to and concerned with what the participant sees and has in mind. Another participant noticed that as she moved both a pair of scissors and a white cardboard that caught its shadow, the shadow's fuzziness was affected. One of us said to her 'I'm a little confused about what you are changing when you move these things back and forth.' This was an observation that, in admitting the teacher-facilitator's confusion, encourages the participant to reveal more of her intention and thought. As this same participant explored the scissors' shadows further, one of us wondered 'what happens if you use another object? Is that easier?' This was a question that supports the exploration through making other materials available to it.

The sort of structure we worked on, through these responses, was one that kept open many possible routes along which the participants' work might develop. This offering of a multiplicity of routes was integral to how we understood our teaching: we looked for our participants' ideas to change as they developed their own activity. Our structure of setting, materials and questions provided openings for participants' spontaneous responses - and playing - with light.

We hoped that our participants might go far enough through such play that - on their own - they might open up questions and investigations.

### ***Opening an Activity with Light and Shadow***

Patches of light and shadow appeared to shift across everyday things. To evoke that depth of experience, we chose materials for our workshops that are familiar in everyday surroundings yet have the potential to be tools for moving beyond such casual uses. We laid these things out on tables and, for convenience, grouped them by function. Light sources were on one table; opaque boards and transparent sheets on another; a third held tools and other utensils.

We list our diverse materials to suggest the thinking within this aspect of our teaching. You might find other items that are also evocative. In addition to room lights, we provided flashlights, battery-run Christmas candle lights, electric lamps (together with extension cords, power strips, and extra bulbs that were differently frosted or coloured), an overhead projector and votive candles. The opaque and transparent materials included cardboard strips, cardboard boxes, sheets of paper and a roll of paper, aluminum foil, wax paper, black paper, plastic cups and water, transparencies, faceted glass jars, cardboard mailing tubes, soda straws, spaghetti strainer, combs, mirrors, coloured transparent plastic wrap and string. Trays of tools and utensils held crayons, magic markers, scissors, tape and utility knives.

We always provided a few bulbs that were coloured, and a sheet of yellow transparent film. Sometimes these coloured materials were used decoratively, such as for making a two-colour

shade, and sometimes investigatively, as for distinguishing the paths of light from two sources. We found that we had to strictly limit the coloured materials we supplied. Colour is so appealing in itself, that when coloured materials are available, people are drawn to try mixing colours together.

We started each workshop by speaking this question:

*What do you notice happens with the light going through something - any kind of opening - and with light that does not get through something - any kind of obstacle? You can think of this as looking at whatever you come to think shadows and non-shadows are.*

*We have lots of materials and we encourage you to combine, cut, change, improvise with them, in whatever ways become useful for finding out more from what begins to intrigue you about what light does... We encourage you to work in groups; you can work separately and in combinations.*

A more specific question: What do you come to notice about light that has gotten through or past a barrier that you make?

We printed the first question on a handout. We hoped it might keep present our encouragement for openness; we did notice that the page's remaining blank space was often used for writing notes.

### **Transitions and Stories from the Activities**

Each workshop evolved quite differently, yet similar transitions arose in each. Too much was going on at once for us, the teachers, to follow all the individual paths developing within each project. So it was by noticing transitions in how the work went, which approximately coincided among all the groups, that we became aware of participants' involvement in their activities and the issues that were arising for them. Along with these transitions, we changed how we interacted: from assisting participants to find what they wanted (such as electric plugs), to holding a flashlight or string for a group needing extra hands, to asking a question or suggesting a connection between what different groups were doing.

### ***Transitions with Materials and Interactions***

The first transition was immediate. As soon as we finished speaking our question, participants gathered to select cardboards, foils and tools from the materials tables. Often they returned for something else: maybe lamps, extension cords, tape or markers.

The second transition was underway once participants had something material in their hands. They folded a cardboard, plugged in a lamp or unrolled some foil. The material itself involved them, as some participants described in writing:

*When I saw the colander on the table with the light patterns, I wanted to 'fool' around with that. (November 14, 1997) Right at the beginning of this experience, I was a little nervous because I had no idea how to even start. I guess I was feeling overwhelmed by the*

*possibilities of 'playing' with all the stuff... Once I started to try 'things', I found myself immersed into an experience that I never felt before. I could discover very interesting facts! (November 12, 1997)*

These actions with materials were already conveying (and extending) the participants' thinking about what light might do with those materials. So just by hearing paper being torn, foil crinkling and participants' spoken exchanges such as about where to hold or put something - we could tell this was happening. Soon each group could be distinguished by its unique contraption: paper taped on the wall to catch shadows, a lamp clamped to something up high or placed under a box, and a cardboard mailing tube angled away from a light.

The next transition arose as these forming projects were ready to be tested. Someone would ask the others if it was alright to turn off the overhead lights. Darkness instantly changed the feeling within the room. It heightened awareness of lights and shadows. It also allowed for playfulness in moving lights, and for fascination with shadows and bright spots that extended across room and ceiling.

We felt that this transition - initiated by participants - expressed the depth of the learning developing through this activity. Close notice of any physical effect entails distinguishing it from its background. Turning out the room lights reduced the background of brightness and enhanced the effect of shadows cast by smaller lights they held. This example of a decision to turn out lights was evoked here through the activity. In common with the practice of science generally, it shares the recognition that, by controlling an environment in ways that by choice reduce extraneous things going on in it, the phenomenon of interest may be brought into more distinct relief.

We observed that participants developed further with this understanding as background light superimposed over effects they were trying to make. The room was not uniformly dark, since people were using and directing small lights in every way. Stray light from one group's flashlight might cast a strange neat patch on another group's screen. Sometimes the realisation of what made that patch came suddenly - when the distant source moved or was turned off.

When this was noticed, the usual response was to erect barriers that blocked out extraneous light. However, one group investigated it explicitly. Between their lamp and a paper screen, they had placed a cardboard cut with one vertical slit. Several bright lines appeared on their paper and shifted when someone else's light moved. This so intrigued the participants that they investigated it. Instead of one light source, they used two, with different coloured bulbs. Both lights shone through the same slit in a cardboard, and struck a paper screen positioned beyond the slit. Bright lines of both colours appeared on the screen, in different places. By moving the coloured bulbs and watching what appeared on the screen, they inferred more about the path each light colour took in going through the slit.

We also noticed that the working interactions among participants passed through transitions. Most started off by doing something of their own. Then participants would join together, perhaps by sharing one light source at a table, or by being intrigued by someone's ornately made light-shade or through talking about something they noticed. To these newly forming activities, they brought materials or methods already in use, and selected new ones. In workshops with 10 or fewer participants, there was usually another transition that spontaneously involved everyone in working on one discussion or project.

For some, it was being with a partner at their table that facilitated their transition to becoming involved with the activity. One described this in writing:

*To begin, this was a difficult question to answer. I have found that when I work with a partner, it is easier when we are working together. In this case, we were working together to 'notice what happens.' (November 14, 1997)*

One example illustrates how productive such combined group work could be. One woman held a glass of water in the air while her partner moved a candle around it. Together they marvelled at the bright spots that appeared on the table below. Two other women, who had been changing the relative distance between a flashlight, cardboard cut-outs and the table surface, brought that interest to the first pair. The combined group's experiment was different: they set the water glass and candle on the table, at fixed positions, and moved a paper screen towards and away from the glass. In this systematic way, they traced out paths made by light refracted through water and glass.

However, group work did not always bring about such harmonious growth of participants' thinking. In one workshop, a participant dominated what happened in his group. One woman from that group later wrote about how this felt: 'It was especially difficult when there was another strong personality interested in exploring a different direction and I was focused and wanting to run with my direction.'

In that situation, we felt this was an unfortunate loss that we had not averted. If our workshops had continued with additional meetings among the same participants, we would have tried to open discussions for addressing such concerns. In teaching a course, [2] and an independent study group [3] involving similar group activities, we set aside part of each meeting to discuss the experiences of working together. Through our responsibility as teachers for facilitating environments where each learner has space to develop questioning and to sustain that questioning in relation with others, we hope such imbalanced interactions can eventually become addressed, reflected upon, and dealt with by teachers and participants. However, during the brief workshops described here, there was insufficient time for discussing issues of working relationships.

### ***Transitions of Teaching and Reflection***

Across the room many activities were going through change and transitions. We supported this by spending time with individuals and groups to learn more about their work and facilitate it. Sometimes we asked a group to describe their experimental setup.

For example, one of us came to a table where several battery-run candles were wrapped in various materials, and asked how these were made. In responding, the participants showed how a transparent cup they had placed over the light candle (like a lampshade) started their ideas for decorating the cup with coloured markers. From this, they had proceeded to place the candle into a cardboard tube, from which its light emerged in a bright spot, like a flashlight's. They had produced a more complex shade by combining tube and transparent materials. Talking about the sequence of this work made the observations developed through it more apparent to them as well as to the questioner.

We also asked participants for their ideas about what was happening with their materials and about how they interpreted what they saw. We posed such questions in an open way that came from our interest to find out what those ideas were and develop them further (see

Duckworth, 1986, 1991); we were not looking for or soliciting certain kinds of responses. We occasionally asked what a group thought would happen if something specific about their experiment was changed. We made such suggestions when a group said they were stuck or when we suspected a change could open their awareness to further possibilities in these materials (see below).

We found participants became so involved in their activities that there was no easy stopping place for us to bring the hour of activity work to a close. Then we turned the room lights on, to announce 5 or 10 minutes of quiet time. During this time, we asked participants to write what came to their mind: observations and questions about light and shadow, or reflections on their learning. In this way, the writing activity was part of the research they were already doing directly with the materials. Through it they gathered and extended their thoughts, and reflected on what they were unsure about. We asked the following questions and wrote them on the board:

*What did you do? What did you notice? What did you think about what you noticed? What questions about shadow and nonshadow came out of that for you from what you did or what somebody else did or what you did together?*

Evocative questions arose through this writing. We list some here to convey their reflective qualities:

*Is darkness a shadow?*

*Can you make the shadow smaller than the object?*

*What part of the light's journey are we seeing?*

*What happens when light passes through things? If you take the same 'thing' and somehow change things? What is the definition of a shadow?*

After this quiet period, there was still some time left. Next, we encouraged groups to share what they had done. Sometimes they demonstrated effects that arose through their activity. New questions came up in these discussions: about light, instruments that use it (cameras and copy machines), other experiences with light and how they felt as learners during this activity. At the end, we thanked everyone and distributed readings that might encourage further engagements with light and shadow.[4]

### ***Transitions Seen Afterwards***

After each workshop, we met to share impressions, read what participants had written and think about how our teaching might evolve. These discussions were ways of reflecting on the structure we provided for the workshops and the transitions that evolved through them. Here, we interweave our reflections and participant responses from records of the session (January 22, 1999), which was followed by a second meeting involving the same teachers, on the next day.[5]

At this workshop, we provided each group with a small Christmas string light hooked to some batteries. When they got the light going, most groups tried it out by varying the relative position between it and a lace doily, comb or colander. As they did this, the object's shadow changed. Some participants investigated these changes, as one paper described:

*- Comb between light source + white paper*

=> *comb casts shadow*

*Light source closer to comb*

=> *shadow gets smaller but not smaller than actual comb*

- *Comb teeth cast shadow. (January 23, 1999)*

As we interacted with groups, we noticed that some groups did not become engaged by these effects, even as the shadows were changing. These groups moved in quick succession from making one effect to the next. Not pausing or looking closely to notice what was happening and its patterns, they became frustrated. Most did go on to find some other shadow effect that evoked their curiosity to investigate.

While we were with each group, we wondered how we could support participants in noticing more about the shadow effects they had passed over. For example, someone in a group Fiona had joined, asked if the shadows they had made were different darkneses or not. Hoping to encourage them to investigate this more, Fiona asked 'do you think there is a way to see if they are?' Afterwards, she felt her question had 'landed hard'. The group did not stay either with her question, or their own; they went on to make something new with the shadows.

However, one pair felt daunted even to work within the workshop structure at all. One of the two ('Alice') reread our question many times and said 'I don't think I can do this'. She did not feel she could be open, to notice and try something of her own. She was not a science teacher and said she believed she had to be told what to do in science. Even as she and her partner moved a light and a doily, making shadows that changed, they stopped, saying they could not do it.

Elizabeth spent part of the session with this pair, to support them through these frustrations. Eventually, the pair observed something that genuinely concerned them. They noticed that the candle's light shone in all directions, making a diffuse glow on the table, but that the light from a penlight made a small distinct circular patch on the table. They wanted to know if the penlight's casing was involved in producing that circle: would the bulb that was inside the penlight shine in all directions (like the candle) or not? Elizabeth assisted them in taking the penlight apart and connecting its bulb to a battery, so they could see the effect of the bulb's light, on its own. In this way, Elizabeth shared the pair's struggles in making a transition from feeling lost, to forming a question that was uniquely theirs. She was also aware of how tentative the pair felt about their experiment: during the sharing time at the end, they had not mentioned it.

In reflecting on these experiences, we wondered what changes we could make for the next day's workshop. How could we encourage the teachers to look more closely, wonder about something, and form their own engagements and understandings? This discussion brought us to several ideas for the next day. We started the second session by describing some qualities of variation in tone and effect from specific examples of what each group had done the day before. We then asked them to take an effect and explore it more closely, thinking about it through a new question:

*Elizabeth: ... to look more closely at something in these different kinds of darkness and brightness. What do you observe in detail is going on about a shadow or brightness? ...*

We also provided artist's charcoal, graphite and drawing papers, and encouraged them to use drawing as a way of extending their observations. Since we were aware that, in at least one case,

the working relationship between two teachers had not gone smoothly, Fiona asked each teacher to work with a different person as a partner today.

The work that developed during the second session was related to these changes. Each group began to see and describe details within the shadows or brightnesses made by their materials, which they had not noticed the day before. These observations brought them to think about how they interpreted light. The group, as a whole, now had a question: can light go around corners, or not? While each pair shared what they had done, the others considered how that helped with the group's question.

The teachers were still discussing this question at that workshop's end, as we showed colour slides of shadows in nature. One slide, of a shaft of light entering a dark cave, connected particularly with this question. We overheard the teachers exclaim:

*Joan: Oh look! So light can't turn corners?*

*Karen: If it could, it would. [laughing]*

This understanding that light can't turn corners' bears the depth and subtlety of the teachers' playful explorations. The excitement suggests that this was the first time their experiences with light had become extensive enough for them to wonder, to ask a question and to use evidence of their own making in interpreting the behaviour of light. This idea was something they had formed together; with it, they made a transition into the doing and thinking of physics.

This second day, an art teacher was the partner of the teacher who had been so anxious before. Together, the two of them drew the subtle shadings within a candle's shadow. When showing these drawings to the others, this teacher (Alice) at first dismissed what she had done, saying:

*Alice: Half the time we spent looking and drawing... [and half] talking about other things...*

*Fiona: But you have captured what you were seeing in this*

*beautiful drawing! So there are different ways of communicating...*

*Alice: Also when you start to draw or try to draw it, it blows your mind, all the different aspects of light... there are so many layers of shading.*

Through both the activity of drawing and the interest of others around her, Alice had made another transition. She saw and drew something she had never seen before in the shadows: gradation of tone instead of a split between uniform light and uniform dark. Doing this opened the experience of nature it became intriguing to her through her own actions of seeing and interpreting it.

For Alice, the drawing was her understanding. With the charcoal, her hand was interpreting - and extending - what her eye was seeing. She came to this understanding and expressed it without words. So often, the emergence of understanding through learners' actions goes unnoticed by teachers. We are so accustomed to relying on language to gauge what students know; tests, for example, are exercises in language. Even in class discussion, when our students use words that sound like what we expect to hear, we assume they understand.

However, understanding may evolve without language; conversely, language may hide the shallowness of an understanding. So for us, a part of teaching includes supporting understandings that are formed wordlessly, and questioning what students say, to find and develop their meaning. In this case, if we met with Alice again, we might encourage her to draw some other light and shadow effects that differ from what she saw with the candle. Through the new work of drawing, she might

then learn something more.

### ***Tensions in the Transitions between Structure and Background***

For ourselves, Alice, and other participants, tensions arose as we were making the transition from our backgrounds with how science is usually taught, to doing explorative play of our own. Many assumptions about learning and education were lodged within our backgrounds. However, since these were never explicitly disclosed as part of those backgrounds, they invisibly influenced what learning science appeared to be about. We became aware of some ways this background pulled us into tensions, through the responses made by some participants to our workshops. Although no one referred to 'high stakes' testing, somehow that practice stood as a stark, but very real, constraint to feeling that one could play and learn through play.

For example, when instruction is defined by testing, the subject matter is converted into a format of questions and answers that are mapped out in advance by the curriculum preparer. The students' role is to get to the answers correctly and efficiently. The teacher's task is to take all the students along the same path to the same fixed endpoint. By contrast, for our workshops, the subject matter encompassed the phenomena of light and dark that could be produced with the materials we had selected. We hoped our opening question might entice exploration of those phenomena by ways and paths that could have interest and meaning for each learner. There were no predefined answers.

One participant wrote with insight about what it was like to make the transition from expecting that there must be 'answers', to realising that our activity involved learning through doing and investigating:

*What I realised was that after a certain point of exploring, I wanted answers. 'Someone just tell me.' I wondered if this was from my schooling. You know, the teacher wants you to find 'the answer'. Then I realised 'someone' was not going to tell me, so I had to investigate further. (November 14, 1997)*

This reflection makes explicit the contrast between being directed by an external authority, such as 'the teacher' or 'someone else, and finding resources and questions within one's own learning. For this learner, the transition brought about an awareness of becoming autonomous -- and a sense that this enabled ways of going on with learning.

However, some participants could not negotiate this transition. This was experienced most acutely by some pre-service teachers who attended our workshop as one meeting of a required academic course. One undergraduate asked in writing:

*Don't know the point of us doing the activity?....*

*What I learned: That I need a Question-direct to answer w/ the method open for exploration - To learn a concept. [sic] (November 12, 1997)*

This student expected our presentation to provide a specific 'point' or goal. Being dismayed at not finding that, the person felt that a personal 'need' for direction had not been met. Without being told what to do or what 'concept' should result, the student could not recognise any



evidences of learning. Another student (who heard this one talking) wrote a counter-response:

*Someone mentioned that they needed direction or questions in order to guide their process. I would mention that I'm glad that original scientists took the time to sit down and experiment in order to figure out the questions. (November 12, 1997)*

A graduate student in the same class perceived a lack of structure' in our activity:

*I had a lot of trouble getting into the activity. I would have needed more structure to have gotten something out of the activity. I wasn't sure what the objective was*

...

*I have had this sort of unstructured experience [before]... and didn't learn a thing I would have just liked to have known what the purpose of the light lab was and how does this help students learn. (November 12, 1997)*

Again, this student was looking for an 'objective', a stated 'purpose'. In regarding 'structure' as the apparatus that leads students toward such a designated purpose, the student could not make out our different use of structure to support exploration. Instead, the view that students need 'help' to 'get something', objectifies learners without according them autonomy over their own processes. The objective background is so pervasive that other possibilities for structuring learning are curtained off. Thus, during the workshop, the student may not have experienced any tension (between that background and our structure), but just have felt there was nothing to do; there was no transition to be made.

Could such a teacher become intrigued enough to enter experiences with materials and begin to notice the developing of learners' minds in action within these experiences? Surely such a change is possible for everyone who cares about teaching. Perhaps longer sessions with more reflections and sharing would facilitate teachers in making observations and questions about and beyond what they currently do.

Yet even as we continue to believe in the powerful resources within each teacher, for supporting their students' evolving learning, our concern deepens for how the background of 'high stakes' testing imperils the work of teachers and students. Testing constrains and distorts teaching: keeping us from seeing the productivity of students' exploring, and stopping us from teaching in ways that extend the processes of everyone's learning. We then miss even the openings for all the many transitions that can arise so playfully as learners form understandings of their own.

### ***The Shadows and Brightnesses Made by Tubes and Candles***

During the workshops, light and dark became something different from the everyday, for us and our participants. Familiar as it seemed, there was much within light and dark that was still unknown to each of us. The inventiveness of what the teachers did with materials often became a way for them to come upon something in the phenomena of light and shadow that they would not ordinarily have noticed. For example, one group found that a light placed within a spaghetti colander, cast marvelous bright spots around the room; they investigated this effect further by sending the light through tubes and soda straws. Another participant produced a striking image by shining a flashlight through a comb, and then reflecting the comb's shadow bands in a mirror. The making of each

invention was a story of learning; below we develop one of those stories.

It was the first workshop that we presented to teachers other than ourselves (February 26, 1997). We did not know what would unfold, either through our interactions, or in the participants' explorations. Already at the start, two women surprised us by what they did. We tell their story here.

Cardboard mailing tubes, cut to different lengths, were mixed among the materials. We included these tubes, expecting they could be used to make camera-like viewers (by covering one end with a pinhole in foil, and the other with something like wax paper). This was an activity one of us had done previously, while teaching a class of teachers.

However, Claudia and Cathy did something different with the tubes. They placed the tubes *vertically* over lighted candles, like the glass shield over an oil lamp. Claudia said she wanted to see if the different-sized tubes would make different-sized 'circles' of light (coming out at their tops?). However, the candles went out when the tubes went over them. Now, she wanted to understand that: 'When does it [candle] go out? This [long tube] has more air in it, right?... So the candle stays on longer, the longer the tube?'

Claudia and Cathy kept exploring candlelight. They placed the candle by itself on a table (without tubes or other materials around it). On the table beneath that candle, Claudia noticed two shadows. One was a symmetric circle all around the base of the candle; the other extended beyond that circular shadow, but only on one side (Figure 1). Seeing how the long shadow shifted when someone across the room moved a lighted bulb, Cathy inferred that the bulb's light was blocked by the candle stick and cast it as the long shadow.

Claudia wondered about how it seemed 'such an odd thing that the shadow is longer than the thing' casting it. She wanted to make a shadow shorter than the candlestick. Cathy suggested moving the light bulb. In trying this, Claudia got the long shadow to shrink. Cathy then reflected: 'It's like when you are walking when the sun is out'; sometimes your shadow is longer or shorter than you are.

Claudia and Cathy then went on to work out how the candle flame made the circular shadow. This was subtle, for they were making sense of something in negation: an area around the candle that was not illuminated by it, due to how the candle's body obstructed light from its own flame. At the end of this workshop, Claudia wrote on her response page: That size of the circle is related to the flame... and is related to the height of the object. [It] is independent of the light' from the light bulb elsewhere in the room.

In their playful starting arrangements of candles, Claudia and Cathy had come across a complex, two-shadow phenomenon. Intrigue with it motivated Claudia's wonder and questioning, and Cathy's connections to experiences such as the shadows our bodies cast in sunlight. By interacting and researching this together, they sorted out how two independent light sources made these shadows and noticed that shadow length is affected by where the light is and the candle stick's size. This knowledge was both coherent with what light does and, by having come about through their own experience and thought, useful in ways not confined to that particular candle-shadow effect. Through this specific example, Claudia came to see connectedness between light and its shadows, for she started her written reflection with her new understanding: 'Light has a bearing on shadow'.

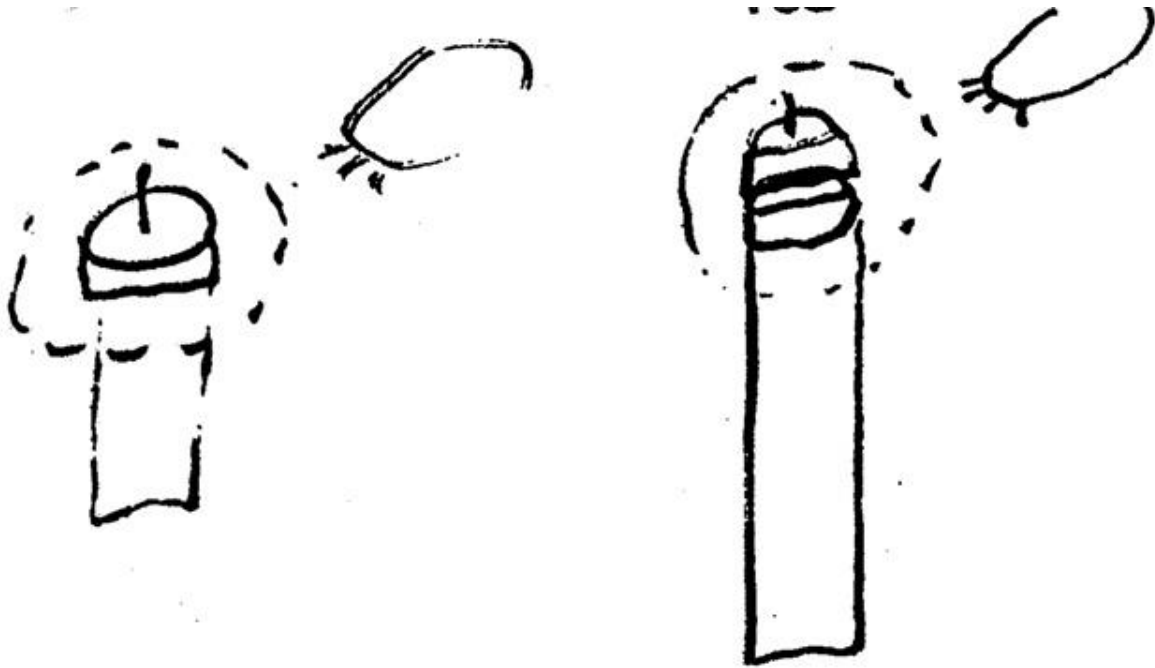


Figure 1. Left: the candle's base blocks the candle flame's light all around it, making a circular shadow (dotted circle). It also blocks light from an external light bulb, making a shadow with a long rectangular shape. Right: when the candle is placed on a short support, the shadow cast by its support and base becomes elongated. The drawing is by a workshop participant (Claudia).

### **Light and Shadow**

Through playing with light, shadows and what makes shadows, we hope learners can begin their own many crossings, back and forth between light and its shadows. This play becomes profound, for it brings our minds into action with the world. A playful action - holding something in light's path; looking for where the shadows fall - can change so much of what there is to see, enlightening what we think and try.

Our changed vision perceives so many shades and paths of light and shadows, of teaching and learning. All these shades and paths are part of what the world is, but are pressed out of view when 'high stakes' testing directs what schools do. We believe that the experiences, of learning and play extended across the opened world, can be so compelling that teachers and learners will continue the experiences. It is their actions, in play, exploration and thought, that can keep the world open and wide, resilient against collapse under the many weights (such as testing) that impose on schools.

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### Notes

[1] Petra Lucht was affiliated with the Harvard Graduate School of Education from 1996 to 1999, during the time we conducted these workshops.

[2] Together we taught 'Exploring Water Through Ways of Doing Art and Physics' at the Harvard Graduate School of Education in Fall 1997.

[3] Elizabeth Cavicchi's dissertation explores the exploratory work of three learners who met with her regularly during a school year (Cavicchi, 1999). [4] The readings included some or all of the following: Newton (1704), Goethe (1810), Plato *Republic VII* (1938), Piaget (1948), ESS (1965), Miller (1982), Duckworth (1990), Gombrich (1995) and Stoichita (1997).

[5] Petra Lucht was not present at this workshop.

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### References

- Cavicchi, E. (1997) Experimenting with Magnetism: ways of learning of Joann and Faraday, *American Journal of Physics*, 65, pp. 867-882.
- Cavicchi, E. (1999) Experimenting with Wires, Batteries, Bulbs and the Induction Coil: narratives of teaching and learning physics in the electrical investigations of Laura, David, Jamie, Myself and the nineteenth century experimenters - our developments and instruments, Dissertation, Harvard University.
- Darling-Hammond, L. (1997) *The Right to Learn: a blueprint for creating schools that work*. San Francisco: Jossey-Bass Publishers.
- Dewey, J. (1916) *Democracy and Education*. New York: Free Press.
- Duckworth, E. (1986) Teaching as Research, in E. Duckworth (1996) *The Having of Wonderful Ideas' & Other Essays on Teaching & Learning*. New York: Teacher's College Press.

- Duckworth, E. (1990) Opening the World, in E. Duckworth, J. Easley, D. Hawkins & A. Henriques (Eds) *Science Education: a minds-on approach for the elementary years*. Hillsdale: Lawrence Erlbaum Associates.
- Duckworth, E. (1991) Twenty-four, Forty-two, and I Love You: keeping it complex, in E. Duckworth (1996) *The Having of Wonderful Ideas' & Other Essays on Teaching & Learning*. New York: Teacher's College Press.
- Duckworth, E. (2001) *'Tell Me More': listening to learners explain*. New York: Teacher's College Press.
- Elementary Science Study (1965) *Light and Shadows*. Watertown: Educational Development Centre.
- Elementary Science Study (1973) *The Elementary Science Study - a history*. Newton: Educational Development Centre.
- Goethe, J. (1810) Coloured Shadows, in C. Eastlake (trans.) *Theory of Colours* (1840). Cambridge: MIT Press.
- Gombrich, E. (1995) *Shadows: the depiction of cast shadows in western art*. London: National Gallery Press.
- Hawkins, F. (1997) *Journey with Children: the autobiography of a teacher*. Niwot: University Press of Colorado.
- Heubert, J. & Hauser, R. (Eds) (1999) *High Stakes: testing for tracking, promotion, and graduation*. Washington DC: National Academy Press.
- Hsueh, Y. (1997) Jean Piaget, Spontaneous Development and Constructivist Teaching. Dissertation, Harvard University.
- Hughes-McDonnell, F. (1996) Understanding High School Physics Students' Perspectives of their Classroom Experiences and their Images of Physics and Physicists. A Pilot Study, Qualifying Paper, Harvard University.
- Hughes-McDonnell, F. (2000) Circuits and Pathways of Learning: 'I can't believe we're actually figuring out some stuff. Dissertation, Harvard University.
- Kaufhold, J. (1998) What's Wrong with Teaching for the Test? *School Administrator*, 16(December), pp. 14-16.
- Lemann, N. (1999) *The Big Test: the secret history of the American meritocracy*. New York: Farrar, Straus & Giroux.
- Lucht, P. (2000) Kaleidoskop Physik. Feministische Reflexionen über das Wissenschaftsverständnis einer Naturwissenschaft, in H. Götschel & H. Daduna (Eds) *PerspektivenWechsel. Frauen-und Geschlechterforschung zu Mathematik und Naturwissenschaften. Talheimer, Reihe 'Kritisches Wissen'*. Mössingen-Talheim.
- Lucht, P. (2001) Zur Herstellung epistemischer Autorität. Die Konstitution des Wissenschaftsverständnisses von Doktorandinnen der Physik an einer us- amerikanischen Universität. Dissertation at the University of Hamburg.
- Madaus, G. (1998) The Distortion of Teaching and Testing: high-stakes testing and instruction', *Peabody Journal of Education*, 65(3), pp. 29-46.
- Mayhew, K. & Edwards, A. (1936) *The Dewey School: the laboratory school of the University of Chicago 1896-1903*. New York: D. Appleton-Century.
- Miller, R. (1982) The Sun Artist Takes a Walk, *Exploratorium*, 5(5), Feb-Mar, pp. 1-23.

- Newton, I. (1704) *Optics, or A Treatise of the Reflections, Refractions, Inflections & Colours of Light*, Book 3, Part 1, Obs. 5-11. London: G. Bell & Sons,
- Perrone, V. (1991) Position Paper. On Standardized Testing, *Childhood Education*, 67, pp. 132-142.
- Phelps, R. (1998) The Demand for Standardized Student Testing, *Educational Measurement: issues and practice*, 17, Fall 1998, pp. 5-23.
- Piaget, J. (1926) *The Child's Conception of the World*. Totowa: Rowman & Allanheld.
- Piaget, J. & Inhelder, B. (1948) The Projection of Shadows, in F. Langdon & J. Lunzer (trans.) *The Child's Conception of Space*. New York: W.W. Norton & Co.
- Plato (1938) *The Republic*, L. Cooper (trans.), Book VII. Ithaca: Cornell University Press.
- Stoichita, V. (1997) *A Short History of the Shadow*. London: Reaktion Books.
- Weiss, J. & Fege, A. (1988) Warning: standardized tests will dictate your curriculum, *Executive Educator*, October 1988, pp. 13-14.