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From the Editor

Wytze Brouwer

Gregory P Thomas, in “The Interview as a Metacognitive Experience for Students: Implications for Practice in Research and Teaching,” addresses the potential of using interviews to get students interested in their own thinking processes and in the nature of science. An interesting conclusion is that the interview not only ascertains how students think but also helps them think about thinking (or gets them metacognitively engaged).

Michael Kohlman, in “Chasing Mechanical Rabbits? The Pursuit of Scientific and Technological Literacy,” traces the long history of the meaning of scientific literacy and the value of a scientific education. A range of views are discussed: Humboldt favoured the pursuit of pure knowledge and the habits of inquiry, Robert Millikan saw physics as an appropriate subject for “weeding out the dullards,” and the 20th century saw war- and economy-related goals of science. More recent authors see the goal of scientific literacy as leading us away from mindless consumerism to a more environmentally sustainable lifestyle.

In “The Influence of Imperial German Science Education and Research on America and Britain, 1871–1941,” Kohlman shows how the focus of scientific research vacillated between pure science (especially before World War I) and science in the service of one’s country or the economy—in Germany and, subsequently, in the United States and Great Britain.

Jill Munro, Marilyn L Abbott and Marian J Rossiter, in “Getting to the Science: Helping English-Language Learners Show What They Know,” discuss how the use of simplified question forms can help new English learners show their subject-area competency.

Arthur Stinner, in “Quantifying Equestrian Show Jumping: A Large Context Problem for Physics Students,” tells the story of the physics behind the running and jumping of show horses. These physics concepts would fit well in the Grades 11 and 12 physics courses.

Frank Weichman, in “A Physicist Does Biology,” describes some of the work he has done on the radiation sensitivity of beetles. Beetles are said to be able to sense forest fires from a distance of 100 km. He investigates the sensitivity of the infrared sensors of the beetles through a series of questions that can be answered by high school mathematics and physics students.

We hear of Bert Millsap’s holiday adventures in “Millsap and the Ring of Fire,” and also his belated comments on a recent education controversy in “Millsap and the No-Zero Policy.”

The Interview as a Metacognitive Experience for Students: Implications for Practice in Research and Teaching

Gregory P Thomas

A Personal Perspective on the Purpose of Educational Research

There is often debate about the purpose and value of educational research and how the findings contribute to the improvement of science teaching and learning. The perception of a disconnection between education researchers and teachers—the metaphorical ivory tower of academia and its distance from the everyday lives of teachers and students—is ever-present in schools and universities.

If one purpose of educational research is to improve education, then teachers' skepticism about the value of engaging in, reading about or supporting educational research is sometimes well founded. Indeed, it could be argued that educational research is a self-sustaining enterprise that, in some ways, has enough momentum to perpetuate itself irrespective of what occurs in schools.

However, because much educational research is publicly funded, direct connections between the findings and improved teaching and learning should be sought out, apparent, communicated and accessible within the education community.

Good educational research, according to Hostetler (2005, 16), is research that not only is methodologically sound but also provides evidence of "beneficial aims and results" and seeks "a sound connection between [the researcher's] work and a . . . justifiable conception of human well-being."

My view is that intention and action are both necessary for good educational research. This article is an action I have undertaken to express my intention to be engaged in such research, and to share findings from a research study so that science educators might consider suggestions to improve the teaching and learning of science. It is about something I learned but did not expect to learn when I began a large research project. It is also about building dialogue about metacognition, a key factor in determining learning success in science and across education.

Metacognition: A Brief Overview

Much has been written about metacognition in education in the last 30 years. Numerous studies have identified the importance of metacognition for learning (Dinsmore, Alexander and Loughlin 2008; Georghiades 2004; Pintrich and de Groot 1990). Students who are more adaptively metacognitive are typically more successful learners than those who are less adaptively metacognitive. *Metacognition* can be defined as one's knowledge, control and awareness of one's thinking and learning processes, as well as those of others (Thomas 2012a).

John Flavell (1976) elevated recent interest in metacognition in education circles, although ideas such as "thinking about thinking" and mindfulness have been considered by philosophers since ancient times.

Metacognitive Knowledge

Metacognitive knowledge can be categorized as declarative, procedural or conditional.

Declarative metacognitive knowledge involves knowing that something is the case, and typically is evident in statements that define a phenomenon or experience. For example, one might declare that "learning is connecting ideas together."

Procedural metacognitive knowledge involves explaining or describing processes or actions one engages in to learn or think. For example, one might say, "When I learn chemistry, I try to visually imagine particles colliding at a molecular level and new arrangements of atoms forming."

Conditional metacognitive knowledge refers to knowledge about when and why particular procedural knowledge is employed. For example, at times it may be beneficial for a student to memorize science information. At other times, it may be more important to look at a concept broadly before exploring the detailed propositions that make up the larger concept. A person with conditional metacognitive knowledge will be able to identify when and why one thinking strategy is more beneficial than another.

Science students should possess metacognitive knowledge that is adaptive for the demands of the science learning environment. They should have a repertoire of thinking and learning strategies they can call to action in order to achieve learning goals. This enables them to be flexible in how they approach learning tasks. They should be consciously aware of their use of metacognitive knowledge and be able to monitor its application as they advance through a learning or cognitive task.

Metacognitive Experiences

Also of importance in considering metacognition is Flavell's (1979) conceptualization of the metacognitive experience. A metacognitive experience is a conscious experience that occurs when one considers one's cognitive and learning endeavours or one's metacognitive knowledge. These experiences are key, as they provide the raw material for reflection that can lead to the development and enhancement of metacognition.

Research suggests that in many cases these experiences are stimulated in students when they, for example, have an "aha!" moment when learning, when they consider the consequences of their learning efforts, or when they discuss thinking and learning processes and strategies with others. The consensus in the science education literature is that a key to stimulating these experiences in schools is developing metacognitively oriented learning environments (Thomas 2003) in which teachers make overt metacognitive demands on students to consider their learning processes, and in which classrooms become primary sites for students and teachers discussing *how* to learn, not just *what* to learn.

Developing Metacognition in the Science Classroom: Moving Forward

Research suggests that most science classrooms are insufficiently metacognitively oriented. However, this situation can be addressed through appropriate professional development, especially PD that is focused on providing pedagogical frameworks for teachers to develop and employ a language of learning (Tishman and Perkins 1997) for discussing learning and learning processes with students; to become more aware of their own thinking and learning processes so that they can be cognitive and metacognitive role models for students (Leou et al 2006; Thomas 2012b); and to find ways to devote more class time to exploring the how-to-learn, as well as the what-to-learn (Thomas and Anderson, forthcoming; Thomas and McRobbie 2001).

There is compelling evidence that metacognition can be developed and enhanced in classrooms characterized by high levels of metacognitive demand, in which teachers challenge students to contemplate how they learn science and how they can improve as science learners. This discussion is best embedded within content-rich learning contexts (Gunstone 1994), as is the norm in science classrooms in Alberta. The thinking and learning processes that should be explored with students should be directly related to the material to be learned. This helps students see the relevance and importance of becoming better thinkers and learners for achieving their learning goals. It also challenges them to have a broader view of science and to consider how they can become better thinkers and learners in general, also important goals for science education.

The Place of the Interview in Metacognition Research

A Current Debate on Methodology

There is ongoing debate in the metacognition research community about how best to study students' metacognition in schools and everyday educational settings. Metacognition is a mental phenomenon, and its presence can be inferred from a variety of data but not observed directly. Therefore, all measures of metacognition might be considered indirect.

Two broad approaches to studying metacognition exist: online and offline (Veenman, Van Hout-Wolters and Afflerbach 2006).

Online approaches explore metacognition and cognition as the person under investigation is engaged in real time with a cognitive or learning task. Typically, the methods employed involve think-aloud protocols, eye tracking, and other forms of recording students' actions and speech. From these recordings, researchers attempt to infer the nature and extent of students' metacognition as it relates to those specific tasks.

Conversely, offline approaches explore metacognition at a time when the person is not involved in real-time engagement with a particular learning or thinking task. Offline approaches typically use a combination of methods, such as interviews, surveys and journals.

Both online and offline approaches have been successfully employed to explore students' metacognition.

When considering the best ways to explore metacognition and the factors influencing it, the approach viewed more favourably by researchers may come down to understanding the nature and degree of inference explicitly and implicitly associated with each method and its respective data. There is a need to understand, in detail, the strengths and weaknesses of a wide range of methods.

In my own research on metacognition, I need to be able to monitor changes to students' metacognition, including the metacognitive knowledge elements of that metacognition and the influence of changes in the classroom environment. How this should be done is a controversial issue in the field of metacognition research. I argue that using multiple methods that do not share the same source of error (Marshall 1996) can enable the collection of convergent data on changes to metacognition or classroom environment. Interviews are an integral part of such a mixed-methods methodology.

The Use of Interviews

Developers of cognitive and metacognitive theories have made substantial use of interviews in their evaluation of the theories and the instruction derived from them. The use of interviews for this purpose continues a long tradition in psychological and educational research. Interviews provide researchers with insights into covert cognitive strategic activities and subjects' knowledge of those activities (that is, metacognitive knowledge), which are inaccessible except when described and externalized by the strategy users themselves.

Student interviews are the main methodological means of eliciting information regarding students' use of cognitive and metacognitive strategies in science education. They constitute prima facie data of what students know, despite students' possibly being unable to report all they might know or lacking the verbal facility to communicate their thoughts accurately.

As with all research methods, caution should be exercised when interpreting interview data. Further, when conducting interviews, there is a need to attend to students' responses and evaluate them for credibility as the interview proceeds. This often necessitates reasking particular questions at staggered times during the interview when the initial response is unclear or potentially inaccurate, or when the interviewee is answering in a way that suggests he or she is trying to second-guess an answer the interviewer might be looking for, or is just trying to say anything to please the interviewer. Conducting an interview is about more than just asking questions.

Despite these considerations, interviews have always been an integral element of my mixed-methods research. Examples of questions I would ask in an interview with a student regarding metacognition are shown in the appendix. Note that the word *metacognition* is not used in any of the questions.

In this article, I explore a seldom considered or reported aspect of interviews—potential reactivity. Reactivity occurs when the person being interviewed is affected by the interview process or content in a way that changes him or her, and possibly whatever is being measured or explored.[1] This can influence the phenomenon being explored in the interview or in the larger research project. As will be discussed later, reactivity can be viewed as either a curse or a blessing, depending on the purpose of the interview and the aims of the interviewer.

The Study

Research Context and Goals

Here, I report on one small facet of a larger study I conducted that explored students' metacognition in high school chemistry and physics classes. The participants were students and teachers at a school in a large city in western Canada.

My overall aim for the research was to work with two teachers to help them develop and enhance their students' metacognition related to the learning of chemistry and physics. To do this, the teachers and I collaborated to enhance the metacognitive orientation of the classroom environments through the teachers' use of a language of thinking associated directly with the nature of the science material being taught and learned. Teachers used metaphors and representational frameworks to speak with students about how they might learn the subject material and, in so doing, to develop students' knowledge, control, and awareness of their science thinking and learning processes (that is, their metacognition related to science learning).

Findings from the larger study have already been reported (Thomas 2011, 2013; Thomas and Anderson, forthcoming), and they suggest that when students are explicitly taught representational frameworks as learning tools and when metaphors are used in concert with those frameworks, students' metacognition is enhanced.

An interpretive, mixed-methods methodology was employed in the larger study to investigate changes in students' metacognition as a consequence of changes in what their teachers said, did and asked them to do in relation to their learning in their Grade 11 chemistry and physics classrooms. Methods such as surveys, classroom observation, and video and audio recording of the teacher and students in class (over 16 weeks for each of the two years of data collection) were used to provide insight into students' cognition and the classroom environment. Interviews were used to collect data that could be used to triangulate the data collected via other methods and to confirm or disconfirm assertions arising from the data analysis.

This article focuses on understanding the possible reactivity of the interviews with students and how they stimulated metacognitive experiences. In focusing on this specific matter beyond the findings already reported, implications for the practices of both teachers and researchers arise for consideration.

The participants focused on here were 27 students taking Chemistry 20 in the second year of the larger study. Informed consent was sought and received from the teacher, the students and the parents/guardians, as per the Canadian Tri-Council guidelines, the regulations of the relevant Research Ethics Board of the University of Alberta and the regulations of the school board.

Data Collection and Analysis

As part of the process of a hermeneutic dialectic circle (Guba and Lincoln 1989), 13 of the 27 students were interviewed. This process is structured so that interviews with participants continue until no new information comes to light, thereby suggesting that any variations in a participant population's perceptions or experience of a phenomenon have been accessed and the researcher can then construct a consensus on the nature and extent of the variations.

The interviews took place in the chemistry classroom during lunch and were conducted in a relaxed, informal manner. They followed a typical semi-structured interview format. A one- to two-minute introduction was followed by a period of 10–15 minutes in which students were asked questions related to the primary research focuses. Examples of the questions asked can be found in the appendix. These questions were not asked in any particular order. Rather, they were integrated as seamlessly as possible with the conversational format of the interview, to enable the interviewer to follow and explore information and leads presented by students during the interview.

In a concluding period of two to three minutes, students were asked to summarize what they thought were the key points they had made in the interviews. They were then asked further questions, such as the following:

- Is there anything you've learned today from doing the interview with me?
- Have you thought about anything that you haven't thought about before?
- Has the interview been useful for you in any way?

The purpose of these questions was to explore the impact and potential benefits of the interview for the students from their own perspectives. They were also meant to explore the potential reactivity of the interview, and from there discern whether the interview served as a metacognitive experience for students. Students were not pressured or prompted to come up with answers to these questions. The questions were simply added to the end of the interview to explore how students might respond.

The students' responses to the questions were coded and categorized. The coding system emerged only after careful review (and more than once) of all the responses for content and meaning. The process of coding involved "attaching one or more keywords to a text segment in order to permit later identification of that statement" (Kvale 2007, 105). Categorization of responses followed the coding and entailed "a more systematic conceptualization" (p 105) of the responses, so that the main themes in those responses could be made explicit and reportable.

From this analysis, assertions were constructed that represent the similarities and variations among the responses. These assertions are presented below, along with supporting evidence in the form of quotations from students' interview transcripts. The quotations selected are meant to show the variations among the students' claims, rather than to be all-encompassing. All names are pseudonyms. The use of students' actual words is meant to highlight their voices in presenting the findings, so that the reader can see and consider the impact of the interviews from the students' perspectives. If we want students to be increasingly responsible for their learning, we need to listen to them and allow them to highlight what works for them and what they see as beneficial for their learning (Lensmire 1998; Rudduck and Flutter 2004).

Results

Assertion 1. All students but one reported that the content of the interview related to matters that had not been a consistent or previous focus of their conscious attention.

Students were quick to suggest that the interview contained questions related to matters they had not considered previously. This is clearly evident in their responses to the question "Have you ever thought about these matters before?" Typical responses were as follows:

> I never really thought about that before. It's just that I think about other stuff. (Cecilia)
>
> I never really thought about that in science until right now. (Brandon)
>
> I've never actually noticed this stuff before. . . . [These types of things] just sort of happen naturally. (Peter)
>
> I haven't thought of these things before because it's just so natural to study on your own . . . to study when you have to. It's the same routine every time. I never thought that one day I should do something like this or something like that. It's always been the same. (Sylvia)

One student provided a perspective that indicates how participation in the interview and its content stimulated students to consider matters related to thinking and learning that were previously underconsidered or not considered at all:

> You never think about this usually. But then, when someone interviews you and asks you questions, you wonder, *Why [did] he ask me it?* Then you can think back. . . . *Maybe that's why he interviewed me.* (Colin)

One student, James, reported that the interview did not stimulate him to consider aspects of his thinking and learning that he had not considered before. His reply to the question "Has doing the interview made you consider things you haven't before?" was "Not really, to be honest."

Rather than further question or explore his response, I took it at face value and respected his claim. Any further questioning could have pushed James into a corner where he might think he had to respond in the affirmative. This would have been unethical in that it would have provoked a response beyond the context of the interview in which the interviewer and interviewee move through the interview with mutual respect for each other and each other's views.

Despite James's assertion, it is clear that the interview was not a passive experience for most students. It can be inferred from their responses that they were actively processing what was occurring during the interview and thinking about the matters being discussed with them.

Assertion 2. All students (excluding James) reported that they learned something from participating in the interview.

As well as identifying that the interview had canvassed matters they had either underconsidered or not considered at all, students articulated what they had realized, learned or considered during the interview. This supports the contention that the interview stimulated students to contemplate what was being discussed and informed their perspectives on at least some of the matters under consideration.

The interview stimulated some students to reflect on and question their existing thinking and learning processes. Hildy suggested, "I think this interview helped me because whenever people or me are doing the labs, we don't really focus on what we are thinking during them." Brandon claimed that the interview prompted him to look "even deeper into how to link stuff [ideas]—that connection thing again. For me that's really important. That's how I discover things and understand them."

Olga maintained that the interview led her to be concerned about her lack of knowledge about some of the matters canvassed:

> By you asking about what I feel about chemistry and how I learn it, I realize that I don't know much about it. I don't even know how to describe chemistry, and that's kind of scary because I've been taking it since whenever.

Alison reported that she was now reconsidering her learning and study habits:

> [The interview] made me notice how I learn and my study habits. I think that some of my habits of learning information might not be that great. . . . They're probably not very good . . . because I just look at information and then process it later. I should probably look at it and then think when he's teaching, and try to understand what it means . . . so that if I have questions I can ask him . . . and then I'll have a better understanding of it.

Other students, as exemplified by Dillon, contemplated what might be appropriate indicators of learning and understanding:

> [The interview has] been useful in causing me to think . . . more about how I learn and maybe ways to improve that. And the ideas of having marks . . . like whether having marks are a good indicator of how well you know something. Because a person could be getting really high marks but not understand it.

What is clear is that the interview stimulated students to consider various aspects of their thinking and learning processes related to their learning of chemistry. This is not surprising, as the questions asked in the last two or three minutes of the interview were general and did not target specific thinking and learning processes, allowing considerable flexibility in how students might respond.

Assertion 3. Students suggested ways that the interview might inform their future deliberations about their thinking and learning processes.

Students' responses to the interview questions suggested that they might continue to reflect and act on matters they saw arising from the interview experience.

Katy clearly expressed the interview's potential influence on her future thinking: "I think it will get me to think a little more about science and the way I'm being taught, and thinking about other methods [of learning]." Gareth echoed her: "Now I could probably find out different ways of how I can study chemistry, and then try out different ways and experiment with them. I think I will [do that]."

Colin also thought he should consider alternative learning strategies:

> I can think of what we just talked about and bring it to my studies, like [asking myself,] *Why am I doing it like this? Maybe there's a different way I can do it?* I want to get a better understanding about what "understand" means . . . more than [me] just saying it.

It is noteworthy that these students did not mention the possible involvement of others. Jasmine, in contrast, proposed that other people would play an important role in her reconsideration of her thinking and learning processes:

> I'm going to think about how I think a little more. When I'm studying, I'll think about how I'm doing it and different ways other people do it . . . and compare how they're doing and how I'm doing and see if something they're doing works for me too. [I'll start] with one of my friends, Olga, and ask her what she does and how she remembers stuff.

Her suggestion points again to the diversity in students' responses.

These intimations suggest that students' interview experiences led them to contemplate further potential metacognitive reflective activities they might undertake.

Discussion and Implications

This article describes students' views of the interview process and what they learned from their participation. Students considered their metacognitive knowledge in relation to their chemistry and science learning. Their assertions and the supporting evidence suggest the need to acknowledge that students are not simply passive respondents in any interview process that aims to explore their metacognition, thinking and learning processes, and classroom environment. The interview itself and the ideas students are asked to consider can stimulate students' contemplation and reflection about their thinking and learning processes. In this way, the interview serves as a metacognitive experience for them.

Implications for Research

In educational research circles, the potential reactivity of the interview is often understated or ignored. It seems obvious that it should be considered, or at least recognized as a possibility, in studies that use interviews to explore students' metacognition and thinking and learning processes.

Welzel and Roth (1998) concluded that students' cognition was not stable during interviews and that context affected it. They also suggested that "the activities during the interview process mediated cognition and therefore the assessment outcomes" (p 39), leading them to question the validity of the assessment function of the interview. They asserted that "interviews do not simply assess, but actually scaffold (or interfere with) the cognitive activities of interviewees" (p 40). On the basis of the findings reported in this article, I suggest that the interviews with students initiated and mediated metacognitive reflection during the interview, thereby eliciting metacognitive experiences.

Of course, acknowledging the reactive nature of research methods poses problems for metacognition research and also, I suggest, for much field-based education research in general. It is important for researchers to acknowledge this. In terms of metacognition research, it seems increasingly clear that any method used to investigate students' metacognition will have associated with it some form and level of reactivity. Using mixed-methods methodologies that enable triangulation of data collected via several sources will enable a clearer understanding of metacognition, minimizing the privilege that may be afforded any single method where the reactivity of that method may be problematic.

The extent to which researchers consider reactivity problematic will depend on their aims for themselves, their research and the research participants. My view is that conducting research in schools should be a positive experience for students and teachers, as well as for researchers. This means that students and teachers should learn something that contributes to their "well-being" (Hostetler 2005, 16). This seems a reasonable criterion for research to qualify as good. Interviews with students about their thinking and learning processes provide students with a metacognitive experience that can stimulate metacognitive reflection—key factors in developing and enhancing metacognition. This, I think, has been a positive outcome of my research for students.

Implications for Teaching

From a teaching perspective, the findings point to important implications for science teachers' pedagogical practices. There is no doubt that developing and enhancing students' metacognition should be a key priority in science classrooms (in spite of the lack of suggestions for doing so in science curriculum documents). There is also no doubt that the metacognitive orientation—that is, the extent to which the classroom environment supports the development and enhancement of students' metacognition—is less than satisfactory in many (if not most) science classrooms. This is understandable given that the science content is a high priority in many teachers' minds.

Interviewing students about their thinking and learning processes is one way for teachers to stimulate students' metacognitive reflection and enhance the metacognitive orientation of the classroom. The interview can act as a metacognitive experience for students, and students themselves can see the value of such interviews. Interviews do not have to be long, nor must they be highly structured. They can take the form of informal one-off or ongoing dialogues or conversations with students during which the interviewer (that is, the teacher) seeks to elicit students' knowledge and opinions regarding their thinking and learning processes.

Through answering questions such as those found in the appendix, students can be stimulated to explore their thinking and learning processes, to engage in metacognitive reflection, and to identify strengths and weaknesses in those processes. Through students' self-reports, the teacher can consider whether their metacognition is sufficiently and appropriately adaptive for the demands of the learning environment and the material to be learned. Then, the teacher can make informed decisions as to how to enhance and develop students' metacognition and learning processes, and ultimately students' learning of science.

Appendix: Sample Questions for Exploring Science Students' Metacognition

- What does it mean to learn science?
- How do you learn science?
- What happens inside your head when you try to learn science?

- What strategies do you use when you try to learn science?
- What does it mean to understand science?
- How do you know when you understand science?
- Is the way you learn science similar to or different from how other people learn science?
- Can you tell me how you came to learn science the way you described it to me?
- If you wanted to improve your learning of science, what would you do?

Notes

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1. See http://srmo.sagepub.com/view/encyclopedia-of-survey-research-methods/n448.xml (accessed May 3, 2013).

References

Dinsmore, D L, P A Alexander and S M Loughlin. 2008. "Focusing the Conceptual Lens on Metacognition, Self-Regulation, and Self-Regulated Learning." *Educational Psychology Review* 20, no 4 (December): 391–409.

Flavell, J H. 1976. "Metacognitive Aspects of Problem Solving." In *The Nature of Intelligence,* ed L B Resnick, 231–36. Hillsdale, NJ: Erlbaum.

———. 1979. "Metacognition and Cognitive Monitoring: A New Area of Cognitive-Developmental Inquiry." *American Psychologist* 34, no 10 (October): 906–11.

Georghiades, P. 2004. "From the General to the Situated: Three Decades of Metacognition." *International Journal of Science Education* 26, no 3: 365–83.

Guba, E G, and Y S Lincoln. 1989. *Fourth Generation Evaluation.* Newbury Park, Calif: Sage.

Gunstone, R F. 1994. "The Importance of Specific Science Content in the Enhancement of Metacognition." In *The Content of Science: A Constructivist Approach to Its Teaching and Learning,* ed P J Fensham, R F Gunstone and R T White, 131–46. London: Falmer.

Hostetler, K. 2005. "What Is 'Good' Education Research?" *Educational Researcher* 34, no 6 (August): 16–21.

Kvale, S. 2007. *Doing Interviews.* Thousand Oaks, Calif: Sage.

Lensmire, T J. 1998. "Rewriting Student Voice." *Journal of Curriculum Studies* 30, no 3: 261–91.

Leou, M, P Abder, M Riordan and U Zoller. 2006. "Using 'HOCS-Centered Learning' as a Pathway to Promote Science Teachers' Metacognitive Development." *Research in Science Education* 36, nos 1–2 (March/June): 69–84.

Marshall, H H. 1996. "Implications of Differentiating and Understanding Constructivist Approaches." *Educational Psychologist* 31, nos 3–4: 235–40.

Pintrich, P R, and E V de Groot. 1990. "Motivational and Self-Regulated Learning Components of Classroom Academic Performance." *Journal of Educational Psychology* 82, no 1 (March): 33–40.

Rudduck, J, and J Flutter. 2004. *How to Improve Your School: Giving Pupils a Voice.* London: Continuum.

Thomas, G P. 2003. "Conceptualisation, Development and Validation of an Instrument for Investigating the Metacognitive Orientation of Science Classroom Learning Environments: The Metacognitive Orientation Learning Environment Scale—Science (MOLES-S)." *Learning Environments Research* 6, no 2: 175–97.

———. 2011. "Enhancing Metacognition Related to Chemistry Learning: Students' Conscious Triangulation of Macroscopic, Molecular and Symbolic Representations." Paper presented at the annual meeting of the American Educational Research Association, New Orleans, April 8.

———. 2012a. "Metacognition in Science Education: Past, Present and Future Considerations." In *Second International Handbook of Science Education,* ed B J Fraser, K G Tobin and C J McRobbie, 131–44. Dordrecht, Netherlands: Springer.

———. 2012b. "The Metacognitive Science Teacher: A Statement for Enhanced Teacher Cognition and Pedagogy." In *Contemporary Science Teaching Approaches: Promoting Conceptual Understanding in Science,* ed F Ornek and I M Saleh, 29–53. Charlotte, NC: Information Age Publishing.

———. 2013. "Changing the Metacognitive Orientation of a Classroom Environment to Stimulate Metacognitive Reflection Regarding the Nature of Physics Learning." *International Journal of Science Education* 35, no 7: 1183–207.

Thomas, G P, and D Anderson. Forthcoming. "Changing the Metacognitive Orientation of a Classroom Environment to Enhance Students' Metacognition Regarding Chemistry Learning." *Learning Environments Research.*

Thomas, G P, and C J McRobbie. 2001. "Using a Metaphor for Learning to Improve Students' Metacognition in the Chemistry Classroom." *Journal of Research in Science Teaching* 38, no 2 (February): 222–59.

Tishman, S, and D Perkins. 1997. "The Language of Thinking." *Phi Delta Kappan* 78, no 5 (January): 368–74.

Veenman, M J V, B H A M Van Hout-Wolters and P Afflerbach. 2006. "Metacognition and Learning: Conceptual and Methodological Considerations." *Metacognition and Learning* 1, no 1 (April): 3–14.

Welzel, M, and W-M Roth. 1998. "Do Interviews Really Assess Students' Knowledge?" *International Journal of Science Education* 20, no 1: 25–44.

Chasing Mechanical Rabbits? The Pursuit of Scientific and Technological Literacy

Michael Kohlman

Scientific and technological literacy has been a holy grail of Western science education for at least 50 years. Paul DeHart Hurd (1958), who wrote repeatedly on the subject, is credited with coining the term *science literacy.* Since the term entered the popular lexicon at the height of the Cold War, scientific literacy has been seen as a noble goal worth pursuing, and it has served as a justification for numerous reform and restructuring efforts. Although some scientists, curriculum developers and educational leaders have debated its priority—and its ultimate achievability—it is difficult to find rational arguments flatly opposed to the goal of scientific and technological literacy.

The real challenge has been to find consensus on what *scientific and technological literacy* means and then how to achieve that goal. Sometimes one hears the term *science, technology and society* (STS)—or *science, technology, society and environment* (STSE)—used as a pseudo-synonym for *scientific literacy.* Others have tossed in the concepts of nature of science (NoS) and history and philosophy of science (HPS).

Despite more than five decades of books, journal articles, conferences and spirited debate dedicated to the subject of scientific literacy, the quest continues unabated. Hurd and a number of other science and education academics have become recognized experts, specializing in what is now a staple subdiscipline of science education. Various curriculum reforms have unabashedly listed scientific and technological literacy as a basic objective, but agreed-upon definitions and methods for acquiring (and evaluating) these nebulous concepts remain just out of reach—like mechanical rabbits on a circular track.

This article will review past and present attempts to describe, qualify and justify scientific literacy, and the various reform efforts and curriculum projects that have attempted to "make it so."[1]

Four Centuries of Evolution of a Notion

In his seminal paper, Hurd (1958) traces the quest for scientific literacy back to Francis Bacon and the scientific revolution. He also touches on various efforts by Benjamin Franklin and Thomas Jefferson to implement those ideas in early America.[2] Similar germinal ideas arose in European countries, at various times.

For instance, Charles McClelland (1980) describes the educational reform efforts implemented by Friedrich Wilhelm von Humboldt in Prussia. A renowned linguist, liberal philosopher, influential ambassador and neo-humanist bureaucrat, Humboldt founded in 1810 the University of Berlin (now Humboldt-Universität), which served as his model for the modern German university. Central to his view of education was his philosophy of *Wissenschaftlich* ("spirit of science" or "devotion to science"). For Humboldt and other neo-humanist reformers, such as Johann Gottlieb Fichte,

> the active pursuit of *integrated, meaningful,* and *pure* knowledge was the highest calling of man. . . . This process of personal evolution, of self-development to the limit of one's capacities, was the real goal of higher education, which would thus perpetuate itself long after the student had left the classroom. As for the teacher, who would stay back in the classroom, his passing-on of habits of inquiry and tools for research, plus his living example of a *wissenschaftlich* approach to life, was at least as important as the discoveries of his own personal research or the content of his lectures. (p 124)

The neo-humanist reformers "criticized the Enlightenment exactly for its preference for 'collecting' facts as though knowledge were a mechanical mosaic instead of an organic whole" (p 124):

> *Wissenschaft* and further discoveries emanating from it were the instrument, not the goal, of the scholar. The full development of the personality and of a supple, wide-ranging habit of clear, original thinking was the goal. . . . The defeat of the Frederickian 'machine state' in 1806 [by Napoleon's forces at the Battle of Jena-Auerstedt] had driven home the point that officers and civil servants trained 'by the book,' in the rigid, professional application of specialized expertise, simply caved in, confused, when confronted with new and unusual situations. (p 125)

The role of the state in advocating, shaping, monitoring and funding science education expanded rapidly during this time. While schools and universities saw funding, facilities and resources for science education soar to unprecedented levels, science education was often directed to the service of the state and its interests, rather than the explicit benefit of the individual.

Necessity Is the Mother of Invention, and War Is the Mother of Necessity

During World War II, the life adjustment curriculum, which focused on developing democratic citizens with a broad surface knowledge of how science relates to daily life and society, was in wide practice in the United States (Rudolph 2002). Conceived by progressive educationists in the lean years of the Great Depression, the curriculum enjoyed widespread support from students and parents. However, it was later vigorously criticized by prominent scientists, industrial leaders and ambitious politicians.

As Donahue (1993, 327–28) writes,

> Like professional educators, scientists were concerned about the drop in physics enrollments, yet few of them advocated the kinds of changes recommended by progressives. Instead, they maintained that the basis for teaching physics should be the discipline of physics itself, not its practical applications. The course need not be made easier or more "fun," they argued, but rather its "tough" academic character should be preserved, and proper guidance should steer more students into physics.

Donahue recounts an influential tirade against the life adjustment curriculum by physicist and Nobel laureate Robert A Millikan. In 1941, even before the attack on Pearl Harbor, Millikan weighed in on the debate regarding progressive science curriculum versus rigid, discipline-based pedagogy, on the specific subject of physics instruction:

> Decidedly uninterested in shaping the curriculum to the needs or interests of adolescents, Robert Millikan, the head of Cal Tech's physics department, sided with scientists advocating a strong, discipline-centered physics education. Yet he also saw physics education as serving a purpose larger than simply instruction in basic science; he saw it as the best tool available for meeting the nation's manpower needs, for weeding out the dullards and training the intellectual elite for professional careers. He claimed that physics "is admittedly the best subject in the whole curriculum for testing the analytical aptitudes and capacities of the student." While arguing for universal schooling to offer everyone educational opportunity and to identify talent from the largest possible pool, he went on to say, "Probably the most kindly, the most humane, act that can be done to nine-tenths of the youth of the land is to steer them away from, not toward, these difficult, analytical, intellectual pursuits." (p 328)

At the time, Millikan was a member of a vocal minority, but his ideas were amplified as the international threat of World War II mushroomed into something even more sinister.

During the Cold War, the focus of American science education shifted to producing scientists and engineers at a greater rate than the Soviet rival, to eliminate the perceived threat of a growing knowledge gap. In the period before and after the Soviet launch of Sputnik and the development of the first intercontinental ballistic missiles armed with thermonuclear warheads, there was an avalanche of activity to overhaul science education, with massive federal support and the vast scientific and technical resources of the American military-industrial complex. This surge was also characterized by the fervent efforts of elite scientists and engineers, many of whom were veterans of America's crash wartime science and engineering programs, such as the infamous Manhattan Project and MIT's Radiation Laboratory.

Cecil (1957) profiles influential science academic Homer Levi Dodge, who had been physics chair, dean of the graduate school and founder of the Oklahoma

Research Institute, all at the University of Oklahoma. Dodge launched another vigorous attack on the progressive educationists and their life adjustment science curriculum shortly after the unsettling stalemate of the "Korean Conflict." In 1955, after returning from an extended official trip to Russia to study science education, he had this to say:

> The control of elementary and secondary school education in America is in the hands of "educationists" who for the most part have not studied science and know nothing about it. They are anxious that youth "understand the influence of science in human life," but no word is said about understanding science itself. (p 69)

He went on to say,

> The trouble began when John Dewey said that not knowledge or information but self-realization is the goal of education. . . . Dewey has been confuted and our youth cheated. Since the mastery of sciences—the essential tools of the atomic age—became an absolute necessity, *we need a more demanding, strict, and rigorous discipline.* (p 69)

After providing a deluge of statistics on the lagging of American science and technical education, Cecil asks, "What can we do to put the training in fundamental sciences and mathematics on a basis which will permit us to win the atomic race in either its military or economic aspect?" (p 69). He outlines a multipoint action plan, involving early identification of students with outstanding potential, a separate program and curricula for those promising students, and generous scholarships and financial support for the best and the brightest. He advocates for teacher training programs that eschew progressive or liberal pedagogy and, instead, focus maximum attention on producing subject-matter experts, with higher salaries and better working conditions for master science teachers and professors. Again, he quotes Dodge:

> As a result of the educationist's control of certification and advancement requirements, the teacher is forced into still more advanced work in pedagogy instead of in much-needed courses in scientific subject-matter. Thus is ignorance perpetuated. What is needed is certification and advancement based on nation-wide examinations in subject-matter fields. (p 72)

As a stop-gap measure, Cecil suggests the secondment of industrial scientists and engineers to interim teaching positions in secondary schools and colleges, in a new "National Educational Reserve" for science teachers.

Donahue (1993, 321) recounts the post-Sputnik hand-wringing that blamed the crisis on "the flabby American high school curriculum that was no match for the Soviet Union's merciless regimen of math and science for its brightest students." The race to outdo the Soviets in the classroom quickly vaulted physics to national priority status.[3] In testimony to the US Senate during the Sputnik crisis, two European expatriate scientists attacked the life adjustment curriculum and progressive education methods. Edward Teller, father of the H-bomb, said,

> The Russians are pulling ahead of us in science [because] they drive their children on toward a very solid education, particularly in science, and they drive them on in a really merciless manner. (p 343)

Rocket scientist Wernher von Braun said,

> I do not . . . believe in all these newfangled types of things that are being taught at some schools and colleges these days, like "life adjustment" or "household economy." (p 343)

Donahue also discusses the impact of federal legislation in science and education funding, including the rapid swelling of budgets and spending on physics education through the period. He examines the motivations of physicists in exerting such an unprecedented influence on the relatively neglected field of secondary education. Finally, he documents the rising influence of the National Science Foundation (NSF) and the powerful personalities of its leaders in the development of "radical" new science programs, most notably the Physical Science Study Committee (PSSC) program.

One of these principals was Harry C Kelly, assistant director of the NSF. He served with the MIT Radiation Lab during World War II, and then as a scientific inspector and advisor in postwar Japan, where he was in charge of reorganizing Japanese science. Writing in *The School Review,* Kelly (1959) discusses the rising importance of science and technology in the lives of all, opening his article with the example of the atomic bombs dropped on Japan. (He was one of the first Americans to tour Hiroshima after the blast.) He follows with the assurance that "the leaders in the Soviet Union have learned this fact and are making an all-out effort to exploit science and engineering in the furtherance of their aims," while Americans "spent more than a decade in a continuing cycle of enthusiasm and apathy" when what was needed was "embarking immediately on a strong, co-ordinated effort to strengthen research and education in science and engineering" (p 396).

Kelly then presents a brief history of the creation of the NSF, and its mission in promoting and strengthening scientific research and education. He argues that "the basic problem the United States faces in maintaining its position of world leadership in technology is that of improving the quality of instruction in our high schools and colleges during the approaching period of vastly increased enrolments" (p 399). He presents his case for the NSF's developing and expanding programs to "achieve and maintain excellence" (p 401) in science education, noting the NSF's initial work in creating summer institutes and other training programs. After outlining the problems with contemporary science education as practised in schools, he argues for a complete overhaul of science programs and instructional methods. He writes, "In this crucial activity, the critique of the subject-matter material should be made by the scientific community; the methods of presentation should be worked out jointly by teachers and scientists" (p 403) and "we now feel that our greatest efforts should be directed toward strengthening and satisfying the scholarly needs of high-caliber students who have freely identified themselves with science and engineering" (p 404).

Kelly outlines the major tasks in funding reforms, providing supplemental training for science teachers, designing new course materials and teaching resources, and implementing new science curricula under the overall auspices of the NSF—breaking the centuries-old taboo of direct federal control of public education in the United States. This displacement of local and regional control of public education, teacher training and curriculum development was the thin edge of the wedge.[4]

Despite the concentration on a rigorous, discipline-based approach to science education in order to prepare larger numbers of practising scientists and engineers, there were also respected voices advocating for more general science education programs. In 1960, the National Society for the Study of Education (NSSE) published its annual yearbook entitled *Rethinking Science Education* (Henry 1960). The yearbook encouraged science educators "to produce citizens who understood science and were sympathetic to the work of scientists" (DeBoer 2000, 585). A similar proposal had been made in a 1958 report by the influential Rockefeller Brothers Fund. DeBoer quotes a relevant passage from the report:

> Just as we must insist that every scientist be broadly educated, so we must see to it that every educated person be *literate in science*. . . .We cannot afford to have our most highly educated people living in intellectual isolation from one another, without even an elementary understanding of each other's intellectual concern. (p 586)

If You See a Light at the End of the Tunnel, It Could Be a Speeding Train

As mentioned, an acknowledged originator of scientific literacy as a nominal concept in science education was Paul DeHart Hurd. His short article "Science Literacy: Its Meaning for American Schools" appeared in the October 1958 issue of *Educational Leadership,* which had the theme "Curriculum and Survival."[5] It was found among articles with ominous titles such as "Satellites, Rockets, Missiles: Their Meaning for Education" (Spalding 1958), "Moons and Missiles and What to Do Now" (Wilhelms 1958), "Our Best Defense . . ." (Bills 1958) and "Conservation and Survival" (Hone 1958).

Hurd's article, too, is rife with Cold War references to nuclear weapons, jets, missiles, and all manner of scientific and technological marvels. He refers to Sputnik and the consequent "crisis" in education: in the heightened climate of fear, concern about America's survival was leading to head scratching and public interest in education. Hurd seems to fan the flames with repeated assertions about the uncertain future and the ever-increasing pace of scientific and technological change. He cautions,

> The problems facing American education are complex and urgent. They will not be solved by any simple process of "patching" or "retreading" the existing curriculum. The need is for a perspective of education compatible with the forces of science that are now shaping the ways of men. (p 14)

Hurd's prescription for science education reform to meet the challenges of the times is itself complex and phrased in urgent terms. In addition to advocating for more science courses (from the earliest grades through high school) and more science education and continuing professional development for teachers, he invites scientists to take a more active role in science education:

> Hundreds of scientists are giving help by suggesting experiences of greater potential significance for the development of scientific literacy in the young people of America—a professional responsibility they have too long neglected. One group of scientists has developed a new physics course for high schools. (p 15)

He also encourages leadership by business-industry associations:

> Some business-industry associations have taken the leadership in developing curriculum and guidance materials that are frequently superior to those ordinarily available to classroom teachers. (p 15)

He emphasizes,

> The entire situation is unique in educational history. Never has so much effort been expended to modify the content and teaching procedures of one phase of the curriculum. (p 15)

Hurd acknowledges the difficulty posed by the "tremendous volume of scientific knowledge and concepts from which it is necessary to choose a small per cent to form the content of courses" (p 15). In his vision for a new science education approach, he makes an impassioned appeal for science courses "to be taught somewhere near the frontiers of discovery" (p 16), while not neglecting the history of science and technology. His conclusion includes a call for a reasoned interdisciplinary approach, foreshadowing the STS movement of later times:

> The ramifications of science are such that they can no longer be considered apart from the humanities and the social studies. Modern education has the task of developing an approach to the problems of mankind that considers science, the humanities, and the social studies in a manner so that each discipline will complement the other. . . . Modern science teaching must at many points consider questions related to the processes of social change. This is not a responsibility most scientists would seek but one which must be assumed as science continues to influence more and more directly the life of every person on the earth. (pp 16, 52)

Hurd concludes by urging greater efforts for the education of the gifted and talented. In this, at least, he echoes the program for science education reform proposed by hard-liners such as Millikan, Dodge, von Braun, Teller and Kelly:

> It took a ballistic missile to wake up the American people to a realization that the most underprivileged and undereducated group of students in America is the gifted and the talented. . . . Parents want to know what is really being done for the "bright" youngster. . . . Schools are now charged with the responsibility for devising new curricula and teaching methods that will give the academically gifted educational opportunities at least comparable with those of other students.
>
> What have satellites, rockets and missiles contributed to American education? They have created an awareness of the importance of science and technology to social progress and economic security. The public realizes more clearly than heretofore that it is through the program of schools that science will be advanced and the ideals of a free world perpetuated. (p 52)

If this sounds remarkably different from later conceptions of science literacy and consistent with less enlightened Cold War attitudes, it is not atypical of other educators' bowing to the pressures of the perceived emergency. One might even be excused for confusing this conception of science literacy with a more familiar program for "science and technological mastery." The confusion was to persist past the end of that era.

In the officious act of patriotism known as the *National Defense Education Act* of 1958, America embarked on a program of science education reform that would have long-term deleterious effects on encouraging scientific literacy for all students.[6] Many Cold War educationists (including Hurd, Jerome Bruner and William Pinar) would later regret their compliance in using science education to engage in a sort of escalation of hostilities that left many casualties in its wake.

In the drive to achieve scientific and technological mastery in American schools, colleges and universities, the torch of scientific literacy for the larger public was taken up by other proponents. In a letter published in the prestigious journal *Science,* John Mackenzie (1965) advocates for the use of network television to educate the public:

> Let me give a specific example of the type of TV science program that I think ought to be tried. Consider this hypothetical listing in TV program guides all over the United States: "The Beverly Hillbillies Visit Brookhaven." You may think I'm

> pulling your leg, but I'm not. Give me a good commercial TV writer and a physicist consultant with imagination and a sense of humor, and I'll teach ten million Americans more about the fundamentals of high-energy physics in half an hour than science writers and seminars can get across in the next 50 years. Give me a program called "The Man from UNCLE and the Universe," and I'll do the same thing for astronomy.
>
> The notion that NSF would consider putting up the money for such a project must be assigned to the realm of fantasy-fiction. So I offer a second and possibly more palatable suggestion: in two words, Walt Disney. (p 7)

As the Cold War temporarily thawed (détente) in the latter part of the 1960s, other issues came to the fore, and the call again went out for "universal" scientific literacy and a growing sensitivity to pressing environmental and societal issues. Notions of inclusiveness, equality and democracy competed with the prior focus on selecting and producing elite scientists, technicians and engineers. Spiralling military spending, rampant pork-barrel politics, the debacle in Vietnam, the Watergate fiasco and a multitude of environmental scandals not only eroded public confidence in scientists and government leaders but also further tarnished perceptions of educational authorities and the Cold War goals of science education.

The 1970s saw a renewed interest in integrated programs aimed at science literacy for a broader segment of the student population, especially those who would not pursue science education at the postsecondary level. A number of prominent scientists, educators and writers made important contributions to clarifying notions of literacy, STS interactions and broader goals of science education. Counted among the many were Hurd, James Gallagher, Milton Pella and Morris Shamos.

One of the more illustrative and, to my mind, enlightened visions of scientific literacy was provided by Michael Agin (1974) in *Science Education*. His article summarizes the work of other academics, including Hurd and Gallagher, and he provides "a conceptual framework and some applications of education for scientific literacy." His introduction sets the tone for his framework:

> Everyone in our society has a need for science education. The extent of these needs depends upon the goals and interests of each individual. Some individuals want to make natural phenomena more understandable while others have a desire to make what is known about natural phenomena more useful to man. At the same time, all individuals of our society have a need for a better understanding of basic scientific concepts and activities, not to make them better scientists, but to help them become more knowledgeable citizens. . . . The greatest emphasis in science education should be on this segment of the population. (p 403)

Agin provides a detailed description of *scientific literacy,* as well as a rationale:

> Many individuals use the term "scientific literacy" but fail to give it an adequate meaning; they assume that everyone knows what the concept means. There is, therefore, a need for a more specific definition or description of the concept so that better communication is possible. A frame of reference should be established to help consolidate and summarize the many definitions.
>
> The question "Who is scientifically literate?" has been answered in many ways; several are as follows.
>
> 1. A scientifically literate person knows something of the role of science in society and appreciates the cultural conditions under which science survives, and knows the conceptual inventions and investigative procedures. A scientifically literate person understands the interrelationships of science and society, ethics which control a scientist, the nature of science which includes basic concepts and the interrelationships of science and humanities.
> 2. An educated man should know science in a humanistic way. . . . He should feel comfortable when reading or talking with others about science on a non-technical level.
> 3. A scientifically literate person will be curious about the how and why of materials and events, and will be genuinely interested in hearing and reading about things that claim the time and attention of scientists. . . . He may never create any ideas pertaining to science, but he will be conversant with the ideas that are being considered. (p 405)

Agin provides a list of further attributes of scientific literacy, organized into four general themes (p 406):

- "Appreciate the socio-historical development of science"
- "Become aware of the ethos of modern science"
- "Understand and appreciate the social and cultural relationships of science"
- "Recognize the social responsibility of science"

Agin next turns to implications for instruction for scientific literacy, offering ideas from various other researchers. He considers the interrelationships of science and society, the ethics of science, the nature of science and the relative importance of knowledge of fundamental science concepts. He also attempts to differentiate between science and technology and provides several thematic examples for teaching the dimensions of the interrelationships of science and technology. Among those themes, the following are of particular interest: "Nuclear Energy and Social Implications," "Pesticides and the Silent Spring," "Greek Science and Roman Technology" and "Eugenics—Moral, Immoral, or Amoral?" (p 412).

Agin laments the neglect of the "humanistic nature of science" and the overemphasis on specific scientific knowledge and activities, which he says "overshadows the fact that science, an active enterprise, exists within cultural and social matrices" (p 413). He argues against the artificial divide between the scientific and the cultural communities:

> Science is not merely product and process but an activity that generates concepts about phenomena observed in our physical and social environment. It is an activity that is conducted in a social setting, influences society, and is influenced by society. Curriculum planning based upon product and process, therefore, is not enough. Social ramifications of science should be included.
>
> Individuals should become aware of the products and processes of the scientific enterprise within a social setting rather than a social vacuum. Initially, they may view science as being composed or unrelated domains of "product," "process," and "society." But as they become more mature, they should become increasingly aware of the interrelatedness of these domains. Finally, the scientifically mature individual should view science as a social activity with interrelated and interdependent concepts, methods, applications, and influences. (p 414)

This expanded vision of scientific literacy, within a cultural and social context, was gaining favour with younger academics, as well as veterans of the antiwar and civil rights movements that deeply fractured American campuses and the entire country in the aftermath of the turbulent 1960s. This shift was to continue through most of the 1970s, and led to the flurry of activity to reconceptualize curriculum, as exemplified by the work of William Pinar.

Others, however, were not willing to abandon the tried-and-true principles that saw America through its darkest time. While the Nixon era closed in a theatrical farce of hearings and threatened impeachment, the architects of the Cold War vision of science education would not go down without a fight. In fact, they had to wait only a few years before a new champion of the right wing brought about a resurgence of neoconservatism and rattled the sabers, leading to a new charge of educational reforms and scientific–technological brinkmanship to finally defeat the "evil empire" and re-establish *Pax Americana* in a quasi-religious crusade that was to last over a decade.

Cold War II: The Fear Is Back

An example of the acrimonious soul-searching that followed the Vietnam War, and a host of other blows to the beneficent American view of scientific and technological progress, can be found in an article by Richard Meehan (1979) in the pages of *Science*. Written in the immediate wake of the near-disaster at the Three Mile Island nuclear power plant, the article discusses the "hysterical" reaction of the scientific and engineering community gathered at the Edison Centennial Symposium in San Francisco:

> The distressing events at the Three Mile Island nuclear plant were not part of the agenda, but some speakers and participants deplored what they saw as widespread "scientific illiteracy." They called for public education in science and technology to forestall what one speaker referred to as a "Luddite revolt." . . . To the extent that this view, reminiscent of Sputnik days, represents an instinctive reaction of the scientific community to widespread public dismay with technology, its underlying premise deserves some critical comment.
>
> If, as I am suggesting here, the nuclear safety issue is more of a quasi-religious than a technological conflict, then widespread improvement of scientific literacy is unlikely to improve matters. This is not to suggest that educators do not have an important task before them. Exposure and examination of the ideological aspects of the issue, using both traditional liberal arts and social science techniques, might do more to restore rationality than widespread improvement of scientific literacy. At the very least, development in young scientists and engineers of a critical ability to distinguish

> between technical and pseudo-technical social questions would seem desirable. (p 571)

While this event, and its considerable aftermath, might be hailed as a turning point in the debate on scientific literacy, it was by no means the end of Cold War–style attitudes, or of lobbying for a return to the post-Sputnik curricula and national objectives for science education. Indeed, the Reagan–Bush years saw a resurgence of Cold War rhetoric and a renewed faith in science and technology finally deciding the outcome of the superpower standoff.

In addition to stalwarts such as Teller and other military-sponsored scientists, the illustrious chemist Glenn Seaborg (1983) wrote his own take on the Reagan government's report *A Nation at Risk: The Imperative for Educational Reform* (National Commission on Excellence in Education 1983), even before its publication. Resonating with Teller's impassioned pleas for funding and support for the Strategic Defense Initiative (often referred to as Star Wars), Seaborg sent out a desperate clarion call for education reform. He opens with words from *A Nation at Risk:*

> If an unfriendly foreign power had attempted to impose on America the mediocre educational performance that exists today, we might well have viewed it as an act of war. As it stands, we have allowed this to happen to ourselves. We have even squandered the gains in student achievement made in the wake of the Sputnik challenge. Moreover, we have dismantled essential support systems which helped to make those gains possible. We have, in effect, been committing an act of unthinking, unilateral educational disarmament. (p 219)

He then writes,

> There has been an alarming deterioration of our precollege educational system during the past 15 to 20 years. This adversely affects the capacity of individuals to adapt to the changing demands of our complex age and the ability of our nation to compete in today's world of high technology. The deficiency in the quality and quantity of teaching of science and mathematics . . . is undoubtedly a factor in our country's economic decline. Lack of scientific literacy threatens the efficient, or even adequate, functioning of our democracy in this scientific age. (p 219)

One could be forgiven for thinking it is déjà vu all over again. Despite an ascendant new generation of scientists, educators, politicians and bureaucrats, the old guard prevailed as America put its hopes into regaining its economic, military and political hegemony over an anxious world. DeBoer (2000) sums up this period of neo-right ideology and how it returned the nation's science education programs to an alignment similar to the late 1950s:

> At the same time that the science education community was busy defining itself as a discipline and debating whether science education was primarily about science content or primarily about science-based social issues, the National Commission on Excellence in Education (1983) was issuing its report, *A Nation at Risk: The Imperative for Educational Reform.* The report argued that academic standards had fallen in the U.S. as evidenced by the embarrassingly low test scores of American youth, especially in math and science, and that this poor academic performance was the cause of our declining economic position in the world. The solution was to create a more rigorous academic curriculum for all students built around the basic academic subjects of English, mathematics, science, and social studies, as well as computer science and foreign languages. This would be accompanied by higher standards for all students and new means of assessment and accountability. In 1989, the National Governors Association along with President Bush endorsed the idea of establishing "clear national performance goals" as a way to raise standards in education to "make us internationally competitive" (U.S. Department of Education, 1991). (p 589)

It would take the disintegration of the Soviet Union and the fall of communist dictatorships throughout the former Warsaw Pact countries to restart the more liberal, progressive notions of scientific literacy that had rippled through the American collective consciousness in the 1970s.

The 1990s: A Renaissance of Scientific Literacy, or Just an Intermission Between Wars?

With the fall of the Berlin Wall and the dissolution of Reagan's "evil empire," many looked forward to the much-heralded "peace dividend" and longed for domestic calm and prosperity.[7] The 1990s saw a perfusion of ideas that had first become prominent in the reconceptualization movement of the late 1970s. In science education, the lofty goal of "scientific literacy for all" again became a mantra, and led to a veritable eruption of articles, books, curriculum study projects and official reports. The same principals published updated visions for scientific literacy, at all levels of schooling, and they were joined by a new generation of academics and scholars.

Hurd published a flurry of articles in the 1990s (Hurd 1990, 1991, 1994, 1998). Scientific literacy, and a new thrust to consider technology as an explicit partner, became a hot *fin de siècle* theme for curriculum studies and educational planners.

Hurd (1998) makes a case for modernizing school science in preparation for the new millennium:

> For centuries, the approach to science curricula improvement has been simply to update the subject matter of traditional disciplines. A failure to recognize changes in either the practice of science or shifts in our culture continues. . . . Although the nature of science/technology research today is focused mostly on its functional uses in terms of applications to human welfare and the common good, school science curricula in the same context are practically nonexistent. The proposed national standards, benchmarks, and themes of science in their current state are in the traditional mode of curriculum development, although personal–social dimensions are recognized.
>
> The revolutionary changes in the practice and culture of today's science/technology also call for major changes in how science curricula are developed and how the full meaning of scientific literacy should be defined. . . .
>
> Throughout the first 25 years of today's science education reform movement it has been stated repeatedly that science curricula need to be reinvented to harmonize with changes in the practice of science/technology, an information age, and the quality of life. What is sought is a lived curriculum in which the major instructional standards and intellectual skills are those to enable individuals to cope with changes in science/technology, society, and the dimensions of human welfare. Most science curricula found in schools today are descriptive, focused on the laws, theories, and concepts of presumably discrete disciplines. . . . This venture in science curriculum development recognizes the socialization of science and its relevance to how science impacts our culture, our lives, and the course of our democracy. (p 411)

Hurd goes on to identify essential themes and issues for the future, and to reframe the meaning of *scientific literacy* in terms of a long list of desired behaviours for a "scientifically literate person" (p 413). He concludes with the challenges presented to modern youth, and the curriculum needed to answer those challenges:

> Science education for all students is seen as curricula that can be lived and that students can relate to. In addition, cognitive insights needed by students to select, organize, and utilize science knowledge for a productive life are listed. Students who possess these higher order thinking skills and cognitive strategies are regarded as scientifically literate. . . .
>
> For modern times it is science/technology literacy, a lived curriculum, and an understanding of the current practice of research in science/technology that are needed to make science useful in our lives. (p 414)

Many educators and scientists offered additional ideas and qualifications in the scientific and technological literacy debate. Of particular interest to me is this contribution by Jane Maienschein (1998), who provides an astute distinction between *science literacy* and *scientific literacy,* and the implications for teaching and learning:

> By the broadest definition, more than 90% of Americans are scientifically illiterate—an appalling statistic by anyone's standards and possibly a threat to our well-being. Yet with all this agreement we see astonishing ambiguity—and *two different definitions of scientific literacy* [italics added]. The first emphasizes practical results and stresses short-term instrumental good, notably training immediately productive members of society with specific facts and skills. We call this *science literacy,* with its focus on gaining units of scientific or technical knowledge. Second is *scientific literacy,* which emphasizes scientific ways of knowing and the process of thinking critically and creatively about the natural world. Advocates of the second assume that it is good to have critical thinkers, that scientific literacy is an intrinsic good—on moral and other principled grounds. . . .

> The two approaches are often in tension and have different implications for education, testing, and public funding of science. Promoting scientific literacy requires a new way of teaching for which few teachers are prepared. It stresses long-term process over short-term product and questions over answers. The student may possess less knowledge, but has skills for adapting to the challenges of a rapidly changing world.
>
> Political leaders and educators resist working toward the long-term goals of scientific literacy because of pressures to generate immediate outcomes such as higher test scores or more people . . . trained for technical jobs. In contrast, we advocate integrating the short-term goals of knowing science (facts and skills) and the long-term goals of scientific literacy. We must have a society rich in both critical, creative scientific thinkers and enough knowledgeable experts to do today's work. (p 917)

DeBoer (2000) presents a historical analysis of the changing definition and educational–societal value of scientific literacy. Like other contemporary writers (Bybee 1997; Postman 1995), he laments the practice of creating long lists of required knowledge, behavioural objectives and learning outcomes in a misguided attempt to create a standardized blueprint for achieving literacy. The following excerpt will resonate with any science teacher who has questioned the rigid standardized testing regime in Alberta (or elsewhere), and the imperatives this often imparts to the practice of teaching:

> The tendency recently has been to define scientific literacy as a measurable outcome and to include everything possible in the definition. Since the U.S. government declared that American students should be number one in the world on tests of science knowledge by the year 2000, specific content standards have been identified by both state and federal agencies to define the science program for students so that everyone can become "scientifically literate." The question of whether scores on such tests are a legitimate measure of the state of science education in this country . . . has been asked by some, but for the most part, test results have been accepted as a valid indicator of the current state of affairs and sufficient justification for state and federal governments to exert more control over the direction the science education program should take. (p 594)

DeBoer cites other luminaries in the scientific literacy movement, including Kyle (1996), Millar and Osborne (1998), Shamos (1995) and Wood (1988), on the "negative effects of the present emphasis on standards and high-stakes testing" (p 595):

> [Wood] looked at the effectiveness of state-mandated standards testing as a way to improve students' scientific literacy. He found that standards testing ". . . constrains and routinizes the teachers' behavior, causing them to violate their own standards of good teaching. They feel pressured to 'get through' the materials so students will score well on tests. . . . These unintended consequences of the implemented state policy, instead of improving science teaching and learning, continue to reduce science instruction to the literal comprehension of isolated facts and skills" (p. 631). (p 595)

If the 1990s did not immediately deliver scientific literacy in the United States, the decade did bring a huge increase in state and nationwide standardized testing, with a heavy emphasis on machine-scored multiple-choice formats. The computer revolution and information age allowed a level of centralized control never before imagined. Then 9/11 happened, and everything changed.[8]

"If You're Not With Us, Then You're Against Us"[9]

Three months before the infamous "attack on democracy" in September 2001, George W Bush signed a $1.35 trillion tax cut into law. It included deep cuts to a number of educational and social programs developed by the Clinton administration. In the wake of the attack, the *No Child Left Behind Act* (NCLB) was signed into law in January 2002.[10]

In addition to the rhetorical War on Terror, America became embroiled in real "shooting wars" in Afghanistan, Iraq and elsewhere. These actions have had major repercussions on many aspects of education, including the kinds of programs that might have supported scientific literacy in the new millennium. Crisis has followed crisis, retrenchment has followed reaction, and conservatism has followed the narrowing of goals and emphasis on easily quantified standardized results.

I want to relay two recent Canadian perspectives. The first is from Wolff-Michael Roth, a respected British

Columbian researcher in science education and curriculum studies. "Science and the 'Good Citizen': Community-Based Scientific Literacy" (Lee and Roth 2003) delves into a number of prescient issues in an era of perhaps greater anxiety than the Cold War. It disputes the feasibility of developing true citizenship and literacy in a traditional classroom:

> Students who sit in classrooms, copy notes, and engage in token hands-on activities are unlikely to acquire scientific "habits of mind" because they do not have access to the tools, social situations, and practices that mediate the activities of scientists. . . .
>
> Current practices of science education focus on students' conformity to authoritative knowledge and scientific discourse . . ., whether it is "discovery learning" or traditional lecture-style learning (Roth, 1998). (p 403)

> Classroom research shows that students are generally taught one way of representing "nature" and solving related problems (Roth and McGinn, 1999) and are graded on their abilities to conform, and on their abilities to mimic what they are taught (Roth and McGinn, 1998). Alternative meanings, espoused by the humanities or marginalized cultural groups, are generally ignored and sometimes mocked (Roth and Alexander, 1997). (p 403)

> We question this approach that endorses, often unconsciously and therefore ideologically, science education as an unreflective and uncritical enculturation into scientists' science (Roth, 2001). There is nothing inherently moral about the practice of science. The language games associated with "objectivity," "scientific neutrality," and "impartiality" discourage talk about the political and social aspects of science. This silence in fact allows scientists to retain their morally neutral, "above politics" position while they serve corporate interests opposed to democratic governments, develop instruments of mass destruction, and argue passionately for policies that could well be considered eugenic. (p 405)

Another Canadian science education stalwart and a passionate advocate for scientific literacy is Derek Hodson, of the Ontario Institute for Studies in Education (OISE). Hodson has offered numerous articles, books (including *Towards Scientific Literacy* [2008]) and conference presentations on scientific literacy. One of his oft-cited articles is a 2003 effort, entitled "Time for Action: Science Education for an Alternative Future," which is both a call to action and an alternative science education manifesto. His passionate appeal is articulate, comprehensive and powerful. Eschewing the dominant ecological paradigm and discourse of "eco-efficiency," Hodson liberally draws from the "cult of the wilderness," blended with equal parts of "environmentalism of the poor" (Martinez-Alier 2002), to brew a rich mélange of ecological and social justice, infused with cutting-edge pedagogical and political reforms. The following excerpt illustrates the radical transformative mission of Hodson's brand of scientific, social and environmental literacy and political activism:

> The curriculum proposals outlined here are unashamedly intended to produce activists: people who will fight for what is right, good and just; people who will work to re-fashion society along more socially-just lines; people who will work vigorously in the best interests of the biosphere. It is here that the curriculum deviates sharply from STS courses currently in use. The kind of scientific literacy under discussion here is inextricably linked with education for *political literacy* and with the ideology of education as social reconstruction. The kind of social reconstruction I envisage includes the confrontation and elimination of racism, sexism, classism, and other forms of discrimination, scapegoating and injustice; it includes a substantial shift away from unthinking and unlimited consumerism towards a more environmentally sustainable lifestyle that promotes the adoption of appropriate technology. (p 660)

In a utopia, Hodson's arguments and radical solutions would be almost unassailable, from an enlightened postmodern philosophical perspective. However, even converted environmental romantics "crying in the wilderness" would be skeptical about the chances of such an ambitious and radical science curriculum being implemented (let alone faithfully practised) in anything but the most liberal and privileged private schools. This has been the fate of almost any attempt at radical, transformative change in the past. Hodson's curricular vision is a nonstarter, except as an extreme bargaining position (assuming the opposing advocates are interested in a moderate compromise) or the eventual endpoint of a *sustained* generational shift, whose mainstream takeoff has frustrated futurists since the dawn of the modern environmental movement.

Others, including Hodson's colleagues at OISE, have taken up his clarion call for scientific literacy with a social-environmental heart. One project is of particular interest for its attempt to reclaim inroads made but then annulled by Mike Harris's Conservative government in Ontario. Although the project failed in the short term, it was partially redeemed when Ontario's political tides again shifted. As prophesied in Hodson's (2003) unilateral eco-social justice manifesto, an article by his OISE colleagues Barrett and Pedretti (2006) empirically reveals the typical bureaucratic resistance to "radical" curriculum change, and relinquishment of any real control. In their study of the attempts of a group of Toronto teachers to develop a local STSE curriculum not averse to Hodson's vision (essentially an "if you can't join them, then circumvent them" tale), the authors reveal the closed-door policies of small-c conservative education ministries (and one would be hard-pressed to find a more liberal example elsewhere in Canada). The article's focus is the proposed STSE program and the inherent tensions vis-à-vis the ministry-developed science program. If it is any consolation for the authors, the science curriculum enacted in 2008 under Dalton McGuinty's government probably goes further than any other current program in addressing the issues discussed here, even if it is a considerable dilution of Hodson, Barrett and Pedretti's transformative formulae.

Conclusion

It is a safe bet that the means, methods and measures for realizing meaningful societal literacy in science, technology and the environment will continue to be an educational hot potato. As a product of the Cold War era, and a former disciple of the gospel of objective and rational science and technology, I have been complicit in many of the "sins" of modern science education discussed here. In many ways, I have replicated the system that produced me. In spite of six years of formal postsecondary science education, and twenty years of classroom experience, I had barely even imagined a higher-order state of scientific, technological and environmental literacy. I could have easily continued in a state of ignorant bliss, if fate had not intervened.

The past few years of STS studies as a graduate student in the humanities, sciences and education have sparked more questioning, discussion, thought and soul-searching than my entire previous science education and professional career. Having gone through such a program, I now have a panoramic perspective of what scientific and technological literacy might look like. Although the summit is still clouded in fog, I have seen multiple facets of the mountain, and my view is no longer a flat postcard.

However, my own ongoing conversion to the light side is irrelevant in isolation. The real question is what sort of societal paradigm shift, global crisis or secular conversion is required to translate the scientific literacy dreams of romantics such as Humboldt, Hurd and Hodson into reality. If anyone, or any group, succeeds in clearing the obstacle-strewn path and patenting the magic curricular formula, they just might reap a reward beyond riches—a viable long-term future, not just for themselves but for all the students and citizens they are able to educate and evangelize. Can we ever "make it so"? Or are we doomed to forever pursue mechanical rabbits?

Notes

1. I am thinking of the catchphrase of Captain Jean-Luc Picard. In the utopian futurist vision of *Star Trek: The Next Generation,* it would seem that the historic quest for scientific and technological fluency has been achieved. Science education in this far future does not seem to suffer from the formidable barriers and confusion that have plagued us in the past and now. Even Mr Data masters what has remained elusive to us.

2. For an American academic, tracing anything back to Franklin or Jefferson (or any of the Founding Fathers) is a safe rhetorical tool to garner support and earn valuable "patriot points." Edward Teller did the same to argue for scientific mastery über *alles.*

3. Recently declassified documents have revealed that a US Army–sponsored rocket research team, led by transplanted German rocket wunderkind Wernher von Braun, had already designed a multistage rocket to deploy a small satellite into orbit, and could have launched it at least a year before the Soviets launched Sputnik. They were strictly ordered not to proceed. Eisenhower had already conceived of an international space treaty that would allow outside-the-atmosphere overflights of foreign territory, in order to deploy the surveillance satellites his advisors had proposed for gathering intelligence on Soviet military and atomic facilities. He was privately thrilled by the Soviet "first," as it provided a perfect precedent for American surveillance satellites. The first US satellite (Freedom I) was launched three months after the first Sputnik (von Braun's design). The first true spy satellite (Corona), launched in 1960, provided more information in the first two hours of operation than did years of U-2 overflights. It was these spy satellites that

provided the detailed images of missiles and launchers in Cuba, which ultimately allowed JFK to win the first game of nuclear chicken in October 1962 and narrowly avert atomic Armageddon. One has to wonder if the very public "educational crisis" sideshow was part of a scheme to redirect public attention and conceal American intentions and military, scientific and engineering capability, and to justify huge increases in federal spending and intervention into public education.

4. Consider the now infamous *No Child Left Behind* initiative. Sometimes parodied as No Child Left Alive, it is the most notorious recent federal foray into American K–12 public education, and it reaches new heights of centralized bureaucratic intervention and control.

5. *Educational Leadership* is the journal of the Association for Supervision and Curriculum Development. This organization is a subdivision of the National Education Administration, and a vigorous rival of the NSF for federal funding, especially in the wake of Sputnik.

6. For a detailed examination of the furious debates and infighting that followed the "Sputnik crisis," see *Brainpower for the Cold War: The Sputnik Crisis and National Defense Education Act of 1958* (Clowse 1981).

7. Despite the 1990s being hailed as a new era of peace and prosperity, it did not take long for new enemies (Iraq, North Korea, Islamic fundamentalists) and new threats (cyber security, international terror) to appear and to prompt a new round of military expenditures. Fears of slipping in scientific and technological superiority, economic competitiveness (in relation to China and the Far East in general) and other emergent crises led to clamouring for tighter educational standards, as well as expanded testing and accountability regimes.

8. One of the more fascinating conspiracy stories I have heard is presented in the 2005 independent documentary film *Loose Change*. It provides a detailed argument for the 9/11 attacks to have been orchestrated by the Bush–Cheney administration, in order to gain carte blanche for their domestic and international agendas. It would make for a lively classroom debate or challenging interdisciplinary research project, ironically hitting many of the proposed topics and themes in the "official lists" for scientific and technological literacy. If you dare, check it out on Wikipedia at http://en.wikipedia.org/wiki/Loose_Change_(film), which offers a substantial history and analysis and includes a link to download the film. Whether fact or fiction (or somewhere in between), the film is a fine example of the power of modern media and technology and the importance of scientific and technological literacy in separating fact from fiction, news from edutainment and fantasy from plausibility.

9. Commonly attributed to George W Bush. His actual words, in an address to a joint session of Congress on September 20, 2001, were "Either you are with us, or you are with the terrorists."

10. NCLB is the latest US federal legislation (another was Goals 2000) that enacts the theories of standards-based education reform, formerly known as outcome-based education, which is based on the belief that high expectations and setting goals will result in success for all students. The act requires states to develop assessments in basic skills to be given to all students in certain grades, in order for those states to receive federal funding for schools. NCLB does not assert a national achievement standard; standards are set by each individual state. The act also requires that schools distribute to military recruiters the name, home phone number and address of every student enrolled, unless the student (or the student's parent) specifically opts out. For more information on NCLB, go to http://en.wikipedia.org/wiki/No_Child_Left_Behind_Act.

Bibliography

Agin, M L. 1974. "Education for Scientific Literacy: A Conceptual Frame of Reference and Some Applications." *Science Education* 58, no 3 (July/September): 403–15.

Barrett, S E, and E Pedretti. 2006. "Contrasting Orientations: STSE for Social Reconstruction or Social Reproduction?" *School Science and Mathematics* 106, no 5 (May): 237–47.

Bills, R E. 1958. "Our Best Defense . . . ." *Educational Leadership* 16, no 1 (October): 17–20, 59. Also available at www.ascd.org/ASCD/pdf/journals/ed_lead/el_195810_bills.pdf (accessed April 17, 2013).

Bybee, R W. 1997. *Achieving Scientific Literacy: From Purposes to Practices.* Portsmouth, NH: Heinemann.

Cecil, A R. 1957. "The Soviet Challenge for Technological Supremacy (We Need a Scientist's Bill)." *Peabody Journal of Education* 35, no 2: 67–76.

Clowse, B B. 1981. *Brainpower for the Cold War: The Sputnik Crisis and National Defense Education Act of 1958.* Westport, Conn: Greenwood.

DeBoer, G E. 2000. "Scientific Literacy: Another Look at Its Historical and Contemporary Meanings and Its Relationship to Science Education Reform." *Journal of Research in Science Teaching* 37, no 6 (August): 582–601.

Donahue, D M. 1993. "Serving Students, Science, or Society? The Secondary School Physics Curriculum in the United States, 1930–65." *History of Education Quarterly* 33, no 3 (Fall): 321–52.

Henry, N B, ed. 1960. *Rethinking Science Education.* 59th yearbook of the National Society for the Study of Education (NSSE). Chicago: NSSE.

Hodson, D. 2003. "Time for Action: Science Education for an Alternative Future." *International Journal of Science Education* 25, no 6 (June): 645–70.

———. 2008. *Towards Scientific Literacy: A Teachers' Guide to the History, Philosophy and Sociology of Science.* Rotterdam, Netherlands: Sense Publishers.

Hone, E B. 1958. "Conservation and Survival." *Educational Leadership* 16, no 1 (October): 34–37. Also available at http://shop.ascd.org/ASCD/pdf/journals/ed_lead/el_195810_hone.pdf (accessed April 24, 2013).

Hurd, P D. 1958. "Science Literacy: Its Meaning for American Schools." *Educational Leadership* 16, no 1 (October): 13–16, 52. Also available at www.ascd.org/ASCD/pdf/journals/ed_lead/el_195810_hurd.pdf (accessed March 19, 2013).

———. 1990. "Historical and Philosophical Insights on Scientific Literacy." *Bulletin of Science, Technology and Society* 10, no 3 (June): 133–36.

———. 1991. "Closing the Educational Gaps Between Science, Technology, and Society." In "Science–Technology–Society/Challenges," special issue, *Theory into Practice* 30, no 4: 251–59.

———. 1994. "Technology and the Advancement of Knowledge in the Sciences." *Bulletin of Science, Technology and Society* 14, no 3 (June): 125–31.

———. 1998. "Scientific Literacy: New Minds for a Changing World." *Science Education* 82, no 3 (June): 407–16.

Kelly, H C. 1959. "National Program for Education in the Sciences." *The School Review* 67, no 4 (Winter): 396–408.

Kyle, W C. 1996. "Shifting Ideologies and Science Education." *Journal of Research in Science Teaching* 33, no 10 (December): 1043–44. Cited in DeBoer 2000, 595.

Lee, S, and W-M Roth. 2003. "Science and the 'Good Citizen': Community-Based Scientific Literacy." *Science, Technology, and Human Values* 28, no 3 (July): 403–24.

Mackenzie, J K. 1965. "Letters to the Editor." *Science* 150, no 3692 (October): 7.

Maienschein, J. 1998. "Scientific Literacy." *Science* 281, no 5379 (August 14): 917.

Martinez-Alier, J. 2002. *The Environmentalism of the Poor: A Study of Ecological Conflicts and Valuation.* Northampton, Mass: Elgar.

McClelland, C E. 1980. *State, Society, and University in Germany, 1700–1914.* Cambridge: Cambridge University Press.

McEneaney, E H. 2003. "The Worldwide Cachet of Scientific Literacy." *Comparative Education Review* 47, no 2 (May): 217–37.

Meehan, R L. 1979. "Nuclear Safety: Is Scientific Literacy the Answer?" *Science* 204, no 4393 (May 11): 571.

Millar, R. 2006. "Twenty First Century Science: Insights from the Design and Implementation of a Scientific Literacy Approach in School Science." *International Journal of Science Education* 28, no 13: 1499–1521.

Millar, R, and J Osborne, eds. 1998. *Beyond 2000: Science Education for the Future.* London: King's College London, School of Education. Cited in DeBoer 2000, 599.

National Commission on Excellence in Education. 1983. *A Nation at Risk: The Imperative for Educational Reform.* Report to the nation and the secretary of education, United States Department of Education. Also available at http://datacenter.spps.org/sites/2259653e-ffb3-45ba-8fd6-04a024ecf7a4/uploads/SOTW_A_Nation_at_Risk_1983.pdf (accessed April 18, 2013).

Osborne, J, S Collins, M Ratcliffe, R Millar and R Duschl. 2003. "What 'Ideas-About-Science' Should Be Taught in School Science? A Delphi Study of the Expert Community." *Journal of Research in Science Teaching* 40, no 7 (September): 692–720.

Postman, N. 1995. *The End of Education: Redefining the Value of School.* New York: Knopf.

Rockefeller Brothers Fund. 1958. "The Pursuit of Excellence: Education and the Future of America." In *Prospect for America: Report Number V of the Rockefeller Panel Reports.* Garden City, NY: Doubleday. Quoted in DeBoer 2000, 586.

Roth, W-M. 1998. "Job Preparation or Social Activism and Stewardship? 'Authentic' School Science at the Cross Roads." Paper presented at the Making Connections Conference, Baltimore, Md.

———. 2001. "'Enculturation': Acquisition of Conceptual Blind Spots and Epistemological Prejudices." *British Educational Research Journal* 27, no 1: 5–27.

Roth, W-M, and T Alexander. 1997. "The Interaction of Students' Scientific and Religious Discourses: Two Case Studies." *International Journal of Science Education* 19, no 2: 125–46. Cited in Lee and Roth 2003, 403.

Roth, W-M, and M K McGinn. 1998. ">unDELETE science education:/lives/work/voices." *Journal of Research in Science Teaching* 35, no 4 (April): 399–421. Cited in Lee and Roth 2003, 403.

Rudolph, J L. 2002. *Scientists in the Classroom: The Cold War Reconstruction of American Science Education.* New York: Palgrave.

Seaborg, G T. 1983. "A Call for Educational Reform." *Science* 221, no 4607 (July 15): 219.

Shamos, M. 1995. *The Myth of Scientific Literacy.* New Brunswick, NJ: Rutgers University Press.

Spalding, W B. 1958. "Satellites, Rockets, Missiles: Their Meaning for Education." *Educational Leadership* 16, no 1 (October): 4–6. Also available at www.ascd.org/ASCD/pdf/journals/ed_lead/el_195810_spalding.pdf (accessed April 17, 2013).

US Department of Education. 1991. *America 2000: An Education Strategy Sourcebook.* Washington, DC: US Department of Education. Quoted in DeBoer 2000, 589.

Wilhelms, F T. 1958. "Moons and Missiles and What to Do Now." *Educational Leadership* 16, no 1 (October): 7–12.

Wood, T. 1988. "State-Mandated Accountability as a Constraint on Teaching and Learning Science." *Journal of Research in Science Teaching* 25, no 8 (November): 631–41. Quoted in DeBoer 2000, 595.

The Influence of Imperial German Science Education and Research on America and Britain, 1871–1941

Michael Kohlman

Germany's tremendous success in the late 19th century in building a world-class state-supported system of science education and research, with the consequent rapid development of applied science in partnership with German industry, became a model for educational, industrial and political reforms in Britain and America. The 1871 unification of the historically fractious German states, accompanied by extensive industrialization and the rapid expansion and professionalization of science and technology fields, was coincident with Germany's rise to prominence as a world economic, military and political power. Imperial Germany was seen by other nations as both a serious threat and a template for emulation. The great German universities and technical schools, the new Kaiser Wilhelm Institutes for scientific research (with their emphasis on industrial applications and state interests) and the academically rigorous public secondary education system were widely touted as leading the civilized world.

German confidence in the superiority of its national scientific and educational institutions perhaps reached its peak just before World War I. This confidence allowed an isolated and embargoed Germany to fight on—and almost achieve victory—in the industrial and highly technical world wars of the 20th century. Despite being surrounded by vastly more numerous enemy forces and cut off from foreign sources of strategic raw materials and resources, Germany twice threatened to achieve European dominance and hegemony. Even after two consecutive humiliating defeats, Germany's economic and political power rebounded in recoveries often hailed as miraculous, and its education system is still seen as a world leader today, especially in the natural and physical sciences.

This article examines the growth of state-supported science education and research in Imperial Germany, and the influence on and repercussions for the United States and, to a lesser extent, Imperial Britain.

The evolution of Germany's scientific education and research apparatus has been the subject of many books and articles. Space precludes presenting an extensive history, but interested readers can consult the bibliography for many excellent sources. A reasonably brief and accessible source is Lenoir's (1998) "Revolution from Above: The Role of the State in Creating the German Research System, 1810–1910." He writes,

> Discussions of modern scientific research's organization point to the 19th-century emergence of German research universities as evidence that state investment in nondirected academic research, when coupled with beneficial relations between academic research and industry, and when stimulated by appropriate incentives such as protection of intellectual property in an open, competitive system, can lead to explosive growth in scientific knowledge and rapid improvement of industry. (p 22)

Lenoir discusses the shift "in the organization of academic science" beginning in the mid-1840s:

> The shift during this period was due to competition among different German states for intellectual talent as they vied for cultural leadership of a hoped-for unified Germany. Intense competition existed among the leading state ministries of culture and education to stock their universities with the best professors, now defined as discoverers of new knowledge. . . . In an environment where several universities could compete for a single professor's talents, highly visible scientists were able to make

> laboratory space, assistants, and equipment a condition of their acceptance. These academic market forces meant that nearly every German university got at least a small institute of chemistry, and similar developments occurred in physics and physiology. (p 23)

He also discusses the significance of the establishment of the Kaiser Wilhelm Institutes, from 1871 to 1910:

> [Prior to this], the view that state-supported research at the universities should stimulate industry in certain ways was at best a rhetorical position in the German nation's political and cultural transformation. . . . In the period between 1871 and 1910, however, this situation shifted radically, when the tensions that had earlier characterized the relations between academic and industrial cultures dissolved. This cultural shift was as important as the increased relevance of scientific research to the economic performance of German industry. (pp 24–25)

Many commentators have written of Germany's rapid rise in scientific research and technical-industrial capability (Bown 2005; Charles 2005; Johnson 1990; McClelland 1991; Nachmansohn 1979). The growth of organic chemistry fed and reinforced the development of synthetic dyes, pharmaceuticals, new fuels, explosives and raw materials for a whole range of chemical-based industries that were changing the global power structure.

Germany was also the first country to develop doctorate programs in a variety of scientific disciplines, and German PhDs were in high demand in British and American universities and industry. Also, many foreigners came to Germany to study with master chemists, physicists, biologists and physicians. As long as this source of expert specialist education was open to others, countries such as America or England did not need to invest in such expensive ventures, and they highly valued student and faculty exchange programs.

In 1897, Germany had more than 4,000 chemists in nonacademic positions, while British industry employed fewer than 1,000 (Ede and Cormack 2004, 263). In turn, Germany's meteoric rise to imperial power was leading to disputes over trade, colonial ambitions and political jockeying for supremacy that would culminate in World War I, sometimes referred to as the Chemists' War (Bown 2005, 226). Ede and Cormack (2004, 264) conclude their chapter "Science and Empire" with this synopsis:

> By the end of the [nineteenth] century, Britain was still the most powerful nation on earth, but its position was increasingly being challenged. In the Great Game of the colonial era, Britain had the best colonies and controlled the seas, but Germany had created a scientific and industrial powerhouse and was getting ready to use it. In the conflict that was to come, Germany turned to its scientists, especially its chemists, to overcome its disadvantages. The polite era of amateur gentleman scientists and upper-class academicians was ripped apart. Science was moving from understanding the world to mastering it, and few scientists working in the nineteenth century had any idea just how brutal scientific utility could be.

Numerous elite German chemists played prominent roles in World War I, including the development and deployment of poison gases. German Nobel laureate Fritz Haber, professor at Karlsruhe, became Geheimrat (head) in 1911 of the newly built Kaiser Wilhelm Institute for electrochemistry in Dahlem, just outside Berlin (as did Albert Einstein for theoretical physics). The institute was built with funding from German industry and the Rockefeller Foundation. Haber's renown as a great teacher and as the research chemist who discovered the chemical synthesis of ammonia from atmospheric nitrogen is equalled only by his infamy as the father of chemical warfare (Charles 2005, xvii).

Two wartime quotations from Haber about the role of science and scientists in war are prophetic about the relationship between science and war for the rest of the 20th century (Charles 2005, 161):

> A man belongs to the world in times of peace, but to his country in times of war. (1916)
>
> Every war is a war against the soul of the soldier, not against his body. New weapons break his morale because they are something new, something he has not yet experienced, and therefore something that he fears. We were used to shell-fire. The artillery did not do much harm to morale, but the smell of gas upset everybody. (1918)

Haber became the leader of a newly established Giftgassonderkommando (a unit of engineer specialists for poison gas deployment) composed of many of his former colleagues, subordinates and students from the Berlin Kaiser Wilhelm Institutes. The unit was charged with developing and employing a range of new chemical weapons, on all the battlefronts Germany was fighting on. It is noteworthy that the people in this select group accumulated more Nobel Prizes in chemistry and physics than did all American scientists until after World War II. Haber received his 1918 Nobel Prize for chemistry in June 1920, six months after the official ceremony; he was the first recipient not to be personally presented the award by the King of Sweden (Bown 2005, 1).

Reviled outside Germany, Haber was forced into exile after 1933, along with Einstein, during the Nazi purges of German-Jewish scientists and professors. Many of these refugee scientists joined the Allied war effort, and some played key roles in the defeat of Nazi Germany (Ash and Söllner 1996; Nachmansohn 1979).

The suicide of Haber's wife in 1915 (as well as that of their eldest son, in 1946), his postwar fall from grace, and his death (in 1934) in exile after the Nazi's rise to power mark Haber's story as one of the most tragic and ironic cases in the history of science.

Despite disastrous political and economic collapse, and later global depression, the German Kaiser Wilhelm Institutes system continued through the Nazi era and in 1948 was renamed the Max Planck Institutes. The initial impacts of the Chemists' War on scientific institutions and science education reignited efforts in Britain (and elsewhere) to emulate Germany's science, education and research programs, in the name of self-sufficiency, competitiveness and strategic interests. Not only were pre-war professional contacts severed and scholarships or exchanges cancelled, but the Allies, in imposing their naval blockades, also stopped the vital flow of exported German chemicals, drugs, and scientific-technical equipment and supplies. There was a rush to find alternative sources for the wheels and engines of British industry and to produce domestic substitutes (ersatz), with mixed success. The crisis of the war, with the "flocking to the colours," also partially emptied the universities and technical schools of students and staff with technical or scientific training.

George Haines (1969) devotes an entire scholarly monograph to the topic of German influence on English education and science. He describes the eventual English reaction to the disruption caused by the Great War:

> Under the impact of war, many British industrialists discovered, as so many scientists, journalists, and statesmen had long insisted, that where Germany excelled Britain was weak: in scientific education, in technological research, and in industrial organization. And as the statesmen had followed the German model in social legislation, the industrialists turned also to the example of Germany. Although they might more easily have studied American practices, and to some extent did so, it was their enemy they especially sought to copy. (p 170)

In "Science and World War I," University of Manchester Institute of Science and Technology professor Donald Cardwell (1975) writes about the impact of the Great War on British industry, science and education. He notes the formation of government committees on science education, the increased demand for science teachers and the establishment of a PhD degree in chemistry at Oxford in 1917. He writes,

> From this distance we can, I think, begin to see World War I as a historical turning point in British, and perhaps in world science. It saw the final professionalization of science in Britain, the disappearance of the old devotees (the class to which Darwin and Joule had belonged), the national recognition of science and scientific education, and the setting up of appropriate state and industrial scientific institutions. In a sense Britain was given a second chance—but at what a cost! (p 453)

Like their British allies, before the war Americans had long enjoyed cooperation and partnerships with German scientists, engineers, technocrats and entrepreneurs. The Bayer company was one of the largest pharmaceutical concerns in America, and German export of myriad chemicals, instruments and industrial supplies fuelled the engines of democracy.

Pre-war American scientific journals were eager to publish pieces by visiting German scientists, ministers and ambassadors comparing German science and education with those of the United States. Two articles are typical of the period.

In the first, from the September 1905 issue of the august journal *Science,* Lewellys Barker celebrates an address given by distinguished Berlin anatomy professor Wilhelm Waldeyer, in which he touched on "the relation of Europe (and especially Germany) to American science":

> Waldeyer discussed the matter in a *Festrede* delivered at an open session of the Royal Prussian Academy of Sciences in Berlin early this year. . . . It is the second part of the address which is of chief interest to the readers of *Science,* as it considers the

> special matter of the relation of Europe and of Germany to science in America. The whole address is characterized by a wish for harmonic relations, by a keen desire to foster and favor international scientific intercourse and by a plea for the avoidance of everything in the way of mutual misunderstanding and unseemly discord. It is a liberal and broad-minded statement, certainly as fully lenient to America as one could ask; it can scarcely fail to cement good feeling and to promote intercontinental harmony among scientific men. On adverting to this special topic Waldeyer points out that if two peoples are to cooperate in the work of the advancement of culture, the first necessity is mutual respect between them. Each must have something good, something self-achieved to offer, each must preserve its own individuality. . . . Germans, in order to maintain a healthy and useful relation to American science, must, above all, know how the American thinks about culture and science, what the present position of science and scientific investigation in America really is, and how it is likely to shape itself in the near future. (p 300)

Another contemporary *Science* article concerns the state of higher education in Germany and the United States, written by the registrar of Columbia University, Rudolf Tombo, in 1904. Here is his concluding paragraph:

> Both in Germany and in the United States wonderful progress has been made in recent years in the spread of higher education, and this development may be regarded as a specific manifestation of the general material prosperity which has characterized the life of both countries during the past thirty years. The amazing development of the industrial activities of both nations has found a decided reflection in the rapid increase in the enrollments of the schools of technology and the university faculties of applied science, an increase far above the normal, and illustrative of the modern striving to bring education into closer and closer accord with the living issues and problems of the day. And no harm will result from this tendency, provided the proper ideals are never sacrificed to the popular demand, for there seems to be no cogent reason why the intellectual advancement of a nation should not be in perfect harmony with all those things that constitute the sphere of its practical activity. The future of higher education in Germany and in the United States will be proof against all attacks, provided there is no diminution in the proportion of persons animated by a desire to lead the intellectual life, and provided further that we never cease to adhere to those ideals of scholarship and learning which have contributed in such bountiful measure to Germany's commanding position in the educational world. (pp 76–77)

Five months after America's April 1917 declaration of war against the Central Powers, we have the *Science* article "The Outlook in Chemistry in the United States," from an address given by the president of the American Chemical Society, Julius Stieglitz (1917), himself a beneficiary of the German higher education system. In addition to delving into the accomplishments of American chemists in overcoming the wartime shortages of critical materials, Stieglitz discusses the dire need for more chemists, professors, teachers and science students to meet the greatly increased demand, during the war and in the future:

> The great European war and now our own entry into the world struggle of free democracies against the organized military power of the last strongholds of feudal privilege in western civilization have brought home to the public as never before in the history of the world the vital place which chemistry occupies in the life of nations. What is it, indeed, that is so fundamental in this science that a country's very existence in times of great emergencies and its prosperity at any time may depend on its master minds in chemistry? (p 322)
>
> Looking beyond the immediate future to the years ahead, why should we ever again be dependent on any foreign country for such fundamental needs of a nation as the best remedies for its stricken people—or, enlarging the question—for such fundamental industrial needs as dyes and dozens of finer chemicals, the need of which has seriously handicapped manufacturers and to a certain extent is still interfering with normal activity? . . . Our textile manufacturers and many other branches of industry will be at the mercy of [foreign] competitors, assisted by government direction, unless we have a declaration of chemical independence in this country! (p 324)
>
> It behooves our people to see that the departments of chemistry in our universities and colleges be kept not only prolific as to the output of men . . . but that they also be maintained on such a high level of scientific quality that the product will consist of

> the very best type of men! . . . It has no longer been a question of Berlin or Munich, of Goettingen or Heidelberg; for the prospective chemistry student it has been a choice of Harvard or Johns Hopkins, of Chicago or Columbia, of Illinois or California, the Massachusetts Institute of Technology or Cornell. (p 329)

By the end of 1918, the US Chemical Warfare Service was larger than the German and British services combined, and it represented the largest single collection of scientists in America, until the Manhattan Project. The number of university college spaces for science courses quadrupled between 1918 and 1930, with chemistry accounting for about half (Ede and Cormack 2004, 304–05).

Larry Bland (1977), of the George C Marshall Research Foundation, makes repeated comparisons between German and American science and education programs in his treatise "The Rise of the United States to World Scientific Power, 1840–1940." He discusses the post-WWI phase of science in America:

> Although the NRC [National Research Council] and American scientists generally accomplished little of immediate tactical value to the war effort—American participation was too brief for that—the experience had two profound influences on U.S. science: (1) it infused research into the economy so thoroughly that the rise of industrial research as a major branch of the country's scientific establishment may be dated from the war period; (2) it accustomed scientists to working together on cooperative, large-scale research efforts aimed at the quick solution of immediate problems. In science, as in many other areas, valuable lessons were learned that would be applied during the Second World War.

He also points out that American science benefited from the emigration of German scientists to the United States during and after World War II:

> Although American scientists saw their profession as being on the defensive during the 1930's, the Depression era did not seriously retard the development of science in the United States. This was in sharp contrast to the effects in Europe, particularly in Germany, where Hitler's attempt to create an "Aryan science" drove hundreds of scientists to emigrate to America. The "brain drain" that was much discussed in the 1950's and 1960's began in earnest around 1930. By that year, Thorstein Veblen's 1918 forecast seemed vindicated: "The outlook would seem to be that the Americans are to be brought into a central place in the republic of learning." (pp 88–89)

An analysis of several post-1918 primary and secondary sources dealing with science education reveals some rather consistent commonalities. Many praised the rapid progress of American universities and technical schools in rising to the challenge of turning out more science graduates and engineers. The chronic shortage of qualified, experienced science teachers and postsecondary instructors was frequently mentioned, as was the lack of adequate science resources and laboratory facilities at the secondary level. The see-saw struggle between satisfying demand from industry and government targets, and the counterweight of maintaining high standards of scholarship and technical competence, was a common theme. There were repeated demands for new science curricula and teaching methods, competing with stringent standardized testing programs and increased qualifications for science teachers. Each time a new curriculum appeared, new challenges arose to upset the equilibrium. The Great Depression, World War II, the dawn of the Cold War era and the Soviet threat all contributed to shifting aims and standards.

As mentioned by Bland (1977), the forced exile or coerced emigration of German-Jewish scientists during the Nazi regime had a major impact on American science and higher education. Even before this time, the post-WWI horror stories of gas warfare, the Bolshevik Revolution, the Spanish influenza and the devastation of Europe had made a significant impression on the US public. This is where another prominent German scientist enters the story.

In 1919, news reports of Albert Einstein's theory of relativity, and its partial confirmation that year, began to circulate in American newspapers, academic journals, and popular magazines and books (Cassidy 1995). The motifs and emotions expressed in the media stories hint at the complex nature of Einstein's rapid rise to fame, after Arthur Eddington's May 1919 expedition confirmed one prediction of Einstein's theory, through observing a solar eclipse from disparate locations on earth (p 17).

Perhaps the most interesting source consulted is Marshall Missner's (1985) "Why Einstein Became Famous in America." Missner analyzes the events, press releases, articles and debates that were sparked, beginning in 1919, first by Einstein's theory of relativity and then his visit to America in 1921. The abstract for Missner's article serves as a succinct summary of Einstein's celebrity:

> The initial factor was the sudden great interest in the theory of relativity that developed because of the dramatic way it was announced as being confirmed, and because of the phrases that happened to be associated with it. These phrases were particularly suited to generate interest in America, which at that time was especially xenophobic, suspicious of [European] science, fearful of domination, but also greatly concerned with advancement and self-improvement. The fame of the theory naturally led to curiosity about Einstein, the theory's creator. When Einstein came to the United States in 1921 as part of a Zionist delegation, the warm welcome American Jews gave the delegation, and [its leader and German physicist] Chaim Weizmann in particular, was mistakenly described by the American press as a hero's welcome for Einstein. This led to a complex series of interactions between the Yiddish and English language press that resulted in Einstein being considered a hero and a secular saint. But the xenophobia and suspicion that had played a part in the theory's fame, also contributed to Einstein's growing personal fame. (p 267)

At different points, the legend of Einstein meant very different things and appealed to different groups, depending on the treatment given by the press. In analyzing thousands of documents, Missner identifies several recurring themes in the period before Einstein arrived in America: revolution, relativity, destroyer of space and time, 12 wise men (special and secret knowledge controlled by the few), dreams and the fourth dimension. Missner stresses the staying power of the "12 wise men" theme: with Einstein as "one of them," Americans might be able to keep at bay the chaos of European wars and civil unrest, and perhaps even rise to the top of the world heap (pp 277–78).

Missner describes the effects of this early press, and how it generated intense interest in the United States, immediately after World War I and the Bolshevik Revolution had caused such anxiety:

> In an atmosphere of new forms of government overthrowing and threatening the old, any development in science that was so widely called a "revolution" and a "radical change" was bound to attract attention. Calling [Einstein's] theory "Bolshevism in science," as Charles Poor did in the *New York Times* on 16 November 1919, made explicit a connection that surely had already been made in the minds of many people. (p 275)
>
> America's response to the revolutionary political developments was the "Red Scare," which was only one aspect of a broader xenophobic trend. Other manifestations of this movement were the rejection of United States participation in the League of Nations, the Palmer raids to round up and deport radicals, the rise of the Ku Klux Klan, the passing of rigid quota laws restricting immigration, Sacco and Vanzetti's arrest, the beginning of Henry Ford's anti-Semitic campaign, and the institution of quota systems on Jews in many Eastern colleges. (p 280)

It was in the 1920s that the American eugenics movement reached its height, with extensive collaboration between American and German eugenicists and related organizations that continued to bloom, right up to the American entry into World War II. Einstein eventually charmed America even more so than Europe, and his popular image underwent an almost miraculous transformation and beatification, to the point of his being compared to Moses. In his conclusion, Missner offers insight into understanding Einstein's fame with the American public:

> Einstein's fame in America was by no means inevitable, for it was built on the contingent association of many different factors. The right kind of announcement of his theory's verification occurred; the right sort of phrases were used to describe the theory; the right chords in the public were touched; Einstein came at the right time, when interest in the theory was beginning to run its course; the right kind of mass demonstrations to attract attention were held; Einstein said the right things and had the right kind of appearance and personality; and there was the right kind of group, the American Zionists and the Jewish community in general, to serve as a vanguard.
>
> It is a tale of serendipity—a publicity campaign run by an invisible hand. But it is important to realize that there was always a dark side to Einstein's fame, and while, in general, reverence for him grew, particularly among Jews, the hostility never faded away either. The recent report of the FBI files shows that even years after 1921, there was still the view

> that Einstein was involved in conspiracies of people with un-American views who were going to use esoteric means to subvert American life.
>
> So, together with the view that Einstein was a great genius and a secular saint, there also developed the view that what Einstein had done would enable small groups to use secret and mysterious methods to harness enormous power and thus control the ordinary person's life. The reverential side became the predominant one, but the fearful side never went away, and it made a very significant contribution to the development of Einstein's fame. (pp 290–91)

As Bland (1977) hints, theoretical physics and the academic study of quantum mechanics and relativity theory began in America in the 1930s, although it was not until after the Sputnik launch in 1957 that these topics filtered down to the secondary school physics curriculum (Donahue 1993). The rise of modern physics in America was greatly aided by the arrival of so many German-Jewish émigrés, including Einstein and Leo Szilard. Szilard, with Vannevar Bush, persuaded President Roosevelt to inaugurate the Manhattan Project in 1941, and complete the ascendancy of physics in the hierarchy of American science and science education.

At this time, there was debate over progressive education versus scientific discipline-based pedagogy, on the specific subject of physics instruction at the secondary school level. Donahue (1993, 327–28) writes,

> Like professional educators, scientists were concerned about the drop in physics enrollments, yet few of them advocated the kinds of changes recommended by progressives. Instead, they maintained that the basis for teaching physics should be the discipline of physics itself, not its practical applications. The course need not be made easier or more "fun," they argued, but rather its "tough" academic character should be preserved, and proper guidance should steer more students into physics.

Donahue recounts how American physicist and Nobel laureate Robert Millikan weighed in on the debate:

> Decidedly uninterested in shaping the curriculum to the needs or interests of adolescents, Robert Millikan, the head of Cal Tech's physics department, sided with scientists advocating a strong, discipline-centered physics education. Yet he also saw physics education as serving a purpose larger than simply instruction in basic science; he saw it as the best tool available for meeting the nation's manpower needs, for weeding out the dullards and training the intellectual elite for professional careers. He claimed that physics "is admittedly the best subject in the whole curriculum for testing the analytical aptitudes and capacities of the student." While arguing for universal schooling to offer everyone educational opportunity and to identify talent from the largest possible pool, he went on to say, "Probably the most kindly, the most humane, act that can be done to nine-tenths of the youth of the land is to steer them away from, not toward, these difficult, analytical, intellectual pursuits." Although these opinions were decidedly in the minority in 1941 when Millikan voiced them, the idea of using physics to sort students and serve national manpower needs would receive more attention after World War II, as these arguments were combined with calls for intellectual integrity and discipline-based instruction in physics. (p 328)

This view is reminiscent of German scientists' views before the First World War, or those of the Nazis during their tenure, and is still all too familiar for high school science teachers today.

Cutting off the historical coverage for this article at 1941 was an arbitrary decision, as there is so much of interest in the decades that follow. It is hoped that this brief exposé of the influence of German science education and research on the "victors of the West" has been as informative and "edutaining" for the reader as it was sobering and educational for the author.

In a way, this topic has been a convergence of the science, technology and society (STS) courses I pursued for an education degree. While this article barely scratches the enormous, highly convoluted surface (reminiscent of Einstein's popular explanation of "curved space"), the rest of the story will have to wait for a future, expanded effort. As I am the product of an undergraduate science degree and a technical diploma in chemical technology, the similar trajectories of German and American science and science education are personally familiar to me. I am the inheritor of these influences (along with the diluted British tradition in Alberta schools). Despite the "civilizing influence" of modern, progressive movements in education, the patterns ingrained by Prussian chemists and bureaucrats such as Fritz Haber, American physicists such as Robert Millikan, and British eugenicists and biometricians such as Francis Galton and Karl Pearson run deep. Their legacies have been replicated by many modern states, democratic and otherwise, and have fed into the modern bureaucracies of Western Technopoly (Postman 1992) and its educational institutions.

Let us hope that some knowledge of science's excesses and "horror shows" will temper our sometimes boundless enthusiasm for the utility of science in serving current and future empires, and enlighten the approaches we take in educating the generations to follow.

Bibliography

Ascher, M K. 1937. "A Comparison of Education and National Ideals in Germany and the United States." *The School Review* 45, no 5 (May): 368–80.

Ash, M G, and A Söllner, eds. 1996. *Forced Migration and Scientific Change: German-Speaking Scientists and Scholars After 1933.* Washington, DC: German Historical Institute.

Barker, L F. 1905. "European and American Science." *Science* 22, no 558 (September 8): 299–304.

Ben-David, J. 1971. *The Scientist's Role in Society: A Comparative Study.* Englewood Cliffs, NJ: Prentice-Hall. Cited in Lenoir 1998, 23.

Bland, L I. 1977. "The Rise of the United States to World Scientific Power, 1840–1940." *The History Teacher* 11, no 1 (November): 75–92.

Bown, S R. 2005. *A Most Damnable Invention: Dynamite, Nitrates, and the Making of the Modern World.* Toronto: Viking Canada.

Cardwell, D S L. 1975. "Science and World War I." In "A Discussion on the Effects of the Two World Wars on the Organization and Development of Science in the United Kingdom," special issue, *Proceedings of the Royal Society of London. Series A, Mathematical and Physical Sciences* 342, no 1631 (April 15): 447–56.

Cassidy, D. 1995. *Einstein and Our World.* Atlantic Highlands, NJ: Humanities Press.

Charles, D. 2005. *Master Mind: The Rise and Fall of Fritz Haber, the Nobel Laureate Who Launched the Age of Chemical Warfare.* New York: Ecco.

Donahue, D M. 1993. "Serving Students, Science, or Society? The Secondary School Physics Curriculum in the United States, 1930–65." *History of Education Quarterly* 33, no 3 (Fall): 321–52.

Ede, A, and L B Cormack. 2004. *A History of Science in Society: From Philosophy to Utility.* Peterborough, Ont: Broadview.

Haines, G. 1969. *Essays on German Influence Upon English Education and Science, 1850–1919.* Hamden, Conn: Connecticut College.

Johnson, J A. 1990. *The Kaiser's Chemists: Science and Modernization in Imperial Germany.* Chapel Hill, NC: University of North Carolina Press.

Johnson, T B. 1926. "The Training of Men for the Profession of Chemistry." *Science* 64, no 1647 (July 23): 74–77.

Lenoir, T. 1998. "Revolution from Above: The Role of the State in Creating the German Research System, 1810–1910." *American Economic Review* 88, no 2 (May): 22–27.

McClelland, C E. 1980. *State, Society, and University in Germany, 1700–1914.* New York: Cambridge University Press.

———. 1991. *The German Experience of Professionalization: Modern Learned Professions and Their Organizations from the Early Nineteenth Century to the Hitler Era.* New York: Cambridge University Press.

Missner, M. 1985. "Why Einstein Became Famous in America." *Social Studies of Science* 15, no 2 (May): 267–91.

Nachmansohn, D. 1979. *German-Jewish Pioneers in Science 1900–1933: Highlights in Atomic Physics, Chemistry, and Biochemistry.* New York: Springer-Verlag.

Phillips, D. 1987. "Lessons from Germany? The Case of German Secondary Schools." *British Journal of Educational Studies* 35, no 3: 211–32.

Postman, N. 1992. *Technopoly: The Surrender of Culture to Technology.* New York: Vintage.

Stieglitz, J. 1917. "The Outlook in Chemistry in the United States." *Science* 46, no 1188 (October 5): 321–33.

Thiessen, V. 2003. *Einstein's Gift.* Toronto: Playwrights Canada Press.

Tombo, R. 1904. "Higher Education in Germany and the United States." *Science* 20, no 498 (July 15): 73–77.

Getting to the Science: Helping English-Language Learners Show What They Know

Jill Munro, Marilyn L Abbott and Marian J Rossiter

Researchers such as Bruna, Vann and Escudero (2007) report that many teachers, both in K–12 content areas and in adult academic upgrading, struggle to meet the learning needs of students from diverse linguistic and cultural backgrounds. Others are resistant to changing their assessment practices (Milnes and Cheng 2008). Junior and senior high school teachers often state that English-language learners (ELLs) cannot do the required coursework and, therefore, should not be enrolled in content-area classes until they have the academic and linguistic proficiency to successfully access the structures and objectives of academic coursework (Chamot and O'Malley 1986).

However, sheltered English as a second language (ESL) programs that address K–9 content-area curricula are not common in Alberta, so few programming options are available for ELLs with limited English proficiency. Instead, school administrations usually have no choice but to enroll ELLs in content-area classes with their peers, and teachers are encouraged to provide differentiated instruction and assessments to support them.

In some schools with large ESL populations, if the low-proficiency ESL students were pulled out for specialized instruction, teachers would have few students left to teach. This change in classroom demographics has caused frustration for teachers, who are neither uncaring nor unwilling to teach all types of learners in their classes but are unsure of how to accommodate for ELLs in both their teaching and their assessment of curricular concepts (Milnes and Cheng 2008).

Literature Review

Accommodated Assessment

Research suggests that assessments can underestimate a student's content knowledge if the student is not proficient in the language of the assessment (Abedi et al 2000). The validity and fairness of the use of these assessment tools are a major concern for educators and researchers alike. In the case of Alberta's provincial achievement tests for Grades 3, 6 and 9,

> results are calculated as the percentage of all students in each grade (total enrollment in the grade plus the ungraded students who are in the corresponding year of schooling) who have met the acceptable standard and the percentage who have met the standard of excellence. [A school's] overall result is the weighted average of the result for each test. (Alberta Education 2010, 6)

Thus, ELL students with limited English proficiency are often encouraged to take the provincial achievement assessments.

Accommodation Strategies

Accommodation strategies that support ELLs in completing assessments both *for* and *of* learning differ in their effectiveness and availability. Many teachers adapt their teaching practices to include a variety of learning tasks that help learners, but they are not aware that they also need to help learners develop both their academic literacy skills and their ability to communicate effectively about academic concepts.

Teachers are permitted to adapt their classroom assessment practices to allow a variety of task and response types and to support the learners in their classes. Willner, Rivera and Acosta (2009) assert, however, that there is inadequate research to assist educational governing bodies in choosing the best way to support ELLs in demonstrating their curricular competence on examinations; as a result, many jurisdictions have merely extended to ELLs the list of accommodations available to students with disabilities.

Researchers caution, however, that assessment accommodations must not be allocated in a generalized manner (Kopriva et al 2007; Willner, Rivera and Acosta 2009). They maintain that not all accommodations are suitable or necessary for ELLs, and the accommodation needs of each student are best decided by informed teaching staff working with the student.

A large body of research exists on accommodation strategies for supporting students with special needs in all content areas, and for supporting ELLs in completing high-stakes examinations in social studies and math (Abedi and Lord 2001; Abedi et al 2000). However, little research is available on the use of assessment accommodations for secondary science classes. Although Abedi (2006, 2284) found that "the performance gap was lower for ELLs in science and lowest in math problem solving for items in which the assessment items were less linguistically challenging . . . [t]he performance gap [between ELL and non-ELL students] virtually disappeared in math computation for which the language demands of the test items were minimal." Abedi (2004, 2006, 2009) advocates for reducing the linguistic complexity of test items on high-stakes assessments, as such complexity is irrelevant to the construct being assessed. Abedi also advocates for providing a glossary, either online or in print, to support ELL students' understanding of vocabulary that is not part of the curricular content being assessed.

Supporting ELLs in the Science Classroom

Carrier (2005) recommends that literacy development in science be achieved by directly teaching literacy objectives to science students. These skills would enhance students' ability to read, write and communicate about science concepts, and should include not only vocabulary development but also the academic language functions necessary to discuss science concepts (such as hypothesizing and evaluating). Carrier notes that ELLs face additional learning challenges, because they are developing their English language and literacy skills at the same time as they are learning to "(a) locate information in science texts; (b) interpret and apply that information; and (c) ask, answer, describe, explain, and make predictions about science—all in a language which is still in its developmental stages" (p 5).

Herrera, Murry and Cabral (2007) note that the cultural discourse patterns associated with both written and spoken discourse vary in form and content, and thus it would be beneficial for teachers of ELLs to receive direct instruction in this area.

In addition, Short, Vogt and Echevarria (2011) state the necessity for teachers to explicitly teach students that seemingly everyday vocabulary words (such as *table*) have specific meanings in a science context.

One strategy for facilitating the learning of new concepts for ELLs is to provide students with a range of learning tasks and presentation formats, using a variety of learning modalities to present information. Katz and Olson (2006, 65) encourage teachers to "consider coupling a written assessment with an assessment that uses relational diagrams—such as concept maps or Venn diagrams, drawings, or model construction." These organizers can also help learners connect previous knowledge with new concepts and can act as a visual representation from which students can organize their thoughts prior to completing written or communicative tasks.

Edmonds (2009) suggests that students who have had little experience working in groups may need to work in pairs initially; as they become accustomed to working collaboratively, they can be assigned to work in small groups and then larger groups as their confidence grows.

Additionally, strategies should be implemented that allow students to practise using the accommodations that will be available to them when completing high-stakes tests (such as a reader or CD version, the assistance of a scribe, taped response, extra time and the use of a computer), so that they become comfortable with them (Kopriva 2008; Willner, Rivera and Acosta 2009).

Finally, students should be provided with a variety of response methods and levels of support to help them demonstrate curricular competence. Long-answer questions can be scaffolded with the use of guiding questions or sentence starters so that students are supported with cues to complete longer tasks, such as a lab report (Reiss 2008). Teachers can provide students with simple, uncomplicated questions, minimizing unnecessary linguistic complexity (Abedi 2004).

In addition, tiered questions on assessments and in-class activities can support all learners in demonstrating their curricular competence. According to Richards and Omdal (2007, 429), *tiering* "is the use of the same curriculum material for all learners, but adjusted for depth of content, the learning activity process, and/or the type of product developed by the student." For example, if students are required to label a microscope, the lower-level students can be provided with the necessary terms, the middle-level students with some of the terms and the stronger students with no terms. Differentiated instruction supports all learners, because it provides meaningful tasks for students at a level appropriate to their language proficiency, thus supporting them in meeting the curricular outcomes set by Alberta Education in the program of studies.

Key Accommodated Assessment Strategies

Teachers can use various accommodated assessment strategies for both formative and summative science assessments. The seven key strategies are as follows:

- Pre-teaching of and focus on key vocabulary and language
- Use of graphic organizers
- Use of oral questions to assess comprehension of concepts
- Use of tiered questions
- Use of simplified language structures in questions
- Provision of a reader or auditory support
- Use of scaffolded long-response items

These relatively diverse and easy-to-implement strategies are likely to enhance ELL students' ability to demonstrate their knowledge. Strategies for making assessments accessible while maintaining content integrity are listed in Appendix A and are applied to Alberta Education provincial achievement test items in Appendix B.

Pre-Teaching of and Focus on Key Vocabulary and on Sentence and Language Structures

When focusing on key vocabulary, teachers can choose 10 of the most important terms in a unit and pre-teach those using the Frayer Model. The Frayer Model is used to identify (verbally or pictorially) essential characteristics and examples, and nonessential characteristics and nonexamples, of a given concept.[1]

In addition to the selected content words, teachers should review words of the same word families (such as *differentiate, differ* and *differentiation,* or *solve, resolve, resolution* and *solution*) and the language structures (such as cause and effect, and comparison and contrast) useful in discussing the concepts being studied.

To determine the sentence structures and language focus, teachers should consider the following questions: What do the students need to do with the information presented in the unit? Do they have to make comparisons? Or make causal statements? For example,

- The concave lens makes things look closer than they are.
- The water started to boil because the burner was placed under the beaker.
- If you heat the beaker, then the solution will turn green.

Some example sentence structures are as follows:

- A ____________ lens makes things look smaller.
- The law of reflection states that ____________.

Provide matching activities and then fill-in-the-blank tasks (first with a list of vocabulary, and later without one). See Reiss (2008, 160).

One assessment technique is the use of exit slips. An exit slip is a quick review of the day's lesson that students complete and hand in before leaving the room. These slips can be created as cloze exercises, or even in the form of a graphic organizer. Possible prompts are as follows:

- Three facts that I learned today are . . .
- Three words I want to remember are . . .
- One thing I found very interesting was . . .
- One thing I still have questions about or don't understand is . . .

An entrance slip can also be administered at the beginning of class to review previously taught material.

Graphic Organizers

Graphic organizers (Venn diagrams, mind maps and so on) can be implemented to help students understand content and the relationships between concepts.[2] They can be used as advance organizers at the beginning of a unit to help students get a sense of how a unit, its terms and its concepts are related and to make connections with background knowledge. They can also be used to help learners follow the parts of a lesson and anticipate what is coming next in a class. A key benefit of graphic organizers is that they can be used to present information in a manner that is less daunting to ELLs. They can easily be created using Inspiration software.

Oral Questions in Collaborative Groups

Oral questions can be directed at collaborative groups to assess their comprehension of concepts. The following are some strategies:

- *Think–pair–share.* In this strategy, students work on their own to answer a question, either in class or prior to the class. After they have had time to work alone, they are asked to work with a partner to share their ideas. That pair can then share with another pair. Finally, the whole class can discuss their responses.
- *Numbered heads together.* Students are assigned to small groups, and each member is assigned a number. The groups then review and discuss assigned questions. Finally, one member from each group is randomly selected by number, and shares the group's responses.
- *Gallery walk.* In groups, students create posters showing the important details of the material they have learned. Then, two students from each group present the group's poster and answer classmates' questions as students circulate from poster to poster. Halfway through the allotted gallery walk time, the presenters switch roles with the others in the group.

Tiered Questions

Tiered questions test the same content for students of different English proficiency levels through allowing various types of response. For example, lower-proficiency students could complete an activity that involves matching terms with pictures or definitions; middle-proficiency students could write a definition for each term, or complete a fill-in-the-blanks activity; and the highest-proficiency students could be asked to provide both a definition and an example. Science tests can be modified for lower- and higher-proficiency students; Verplaetse and Migliacci (2008) and Richards and Omdal (2007) provide useful resources for adapting tests in this way.

Simplified Language Structures in Questions

The language in test questions can be modified to reduce the linguistic complexity and cultural references that make these items confusing for ELLs. For example, simplifying questions, avoiding the use of idiom, making abstract concepts concrete and removing complex language structures can all enhance ELL students' ability to demonstrate knowledge (see Appendix A for examples). Abedi (2004, 2006) and Verplaetse and Migliacci (2008) provide a range of options for doing so. However, students need practice with both modified and unmodified question types.

Reader or Auditory Support

A person or a recording device can provide aural forms of test items to students. Some ELLs struggle to read test items, and some are such slow readers that by the time they finish reading a question, they have forgotten it. This accommodation is available to students with special needs, but some ELLs have special needs coding, as well. For this accommodation, particular attention should be paid to the logistics of recording the tests and setting up a suitable setting.

Scaffolded Long-Response Items

Scaffolded tasks include supportive structures that help students provide the information being requested. In a laboratory report, for instance, sentence starters (such as "These results show that . . .") could be provided for each guiding question, or a fill-in-the-blanks format could be used for lower-proficiency students. Students could also answer a series of questions that would elicit information to be used in a lab report, such as the following:

- What was your hypothesis?
- What did you do first?
- What did you do second?
- What did you see/observe?
- What happened next?

Longer test questions could be broken down into their component parts. For example, "In the question above, how many watts were used? What was the unit price? Write the equation that we use to solve this problem. Solve the equation. How much was Susan's electricity bill?" (see Reiss 2008, 135). A "more complex essay question [could be] reduced to a variety of prompts that require only short answers" (Herrera, Murry and Cabral 2007, 40).

Conclusion

The accommodated assessment strategies described in this article can be used to support English-language learners in classes and, consequently, to enhance science teachers' ability to more accurately assess the curricular competence of ELLs. Simplified questions with additional supports allow ELLs to demonstrate their curricular knowledge without the obstacle of the construct-irrelevant challenges presented by linguistically complex question forms. Regular practice and use of the full range of assessment strategies identified here will enable ELLs with developing language competence to show what they know in science.

Appendix A: Strategies for Making Assessments Accessible While Maintaining Content Integrity

The following are the most common recommendations in the literature for increasing the accessibility of questions and enhancing ELL students' ability to demonstrate content knowledge.

1. Use shorter or less complex question forms.
2. Remove extraneous wording and unnecessarily challenging vocabulary.
3. Make abstract concepts concrete by adding examples, elaboration or illustration.
4. Contextualize the questions by relating them to learners' experiences.
5. Avoid the use of idiom and figurative language.
6. Provide a simple glossary of nonessential vocabulary.
7. Use charts, graphs and other visuals, rather than descriptive texts, to present key information and reduce the amount of reading required.
8. Provide sentence stems, guiding questions and graphic organizers to assist with longer-response planning.

Sources: Abedi (2004, 2006); Abedi and Lord (2001); Herrell and Jordan (2008); Herrera, Murry and Cabral (2007); Kopriva (2008); Reiss (2008); Verplaetse and Migliacci (2008)

Appendix B: Science Test Questions with Adaptations

Question 1

From the released items document for Alberta Education's Grade 6 provincial achievement test for science (2008)[3]

Which of the following examples best illustrates the compression of air?

A. Flying a kite
B. Inflating a tire
C. Blowing out a candle
D. Using a vacuum cleaner

Adapted Question 1

Using strategies 1, 2, 3 and 4 from Appendix A

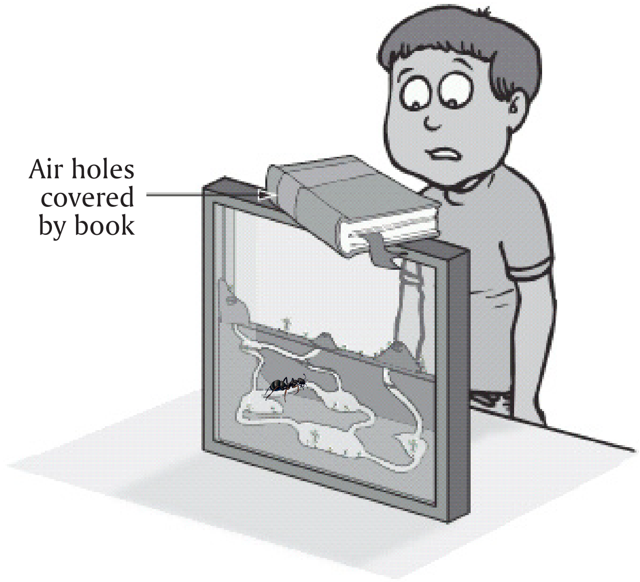
________________ is an example of air compression.

A. Flying a kite
B. Blowing up a balloon
C. Blowing out a birthday candle
D. Using a vacuum to clean the carpet

Question 2

From the released items document for Alberta Education's Grade 6 provincial achievement test for science (2008)

Billy accidentally covered all the holes on his ant farm during lunch hour.

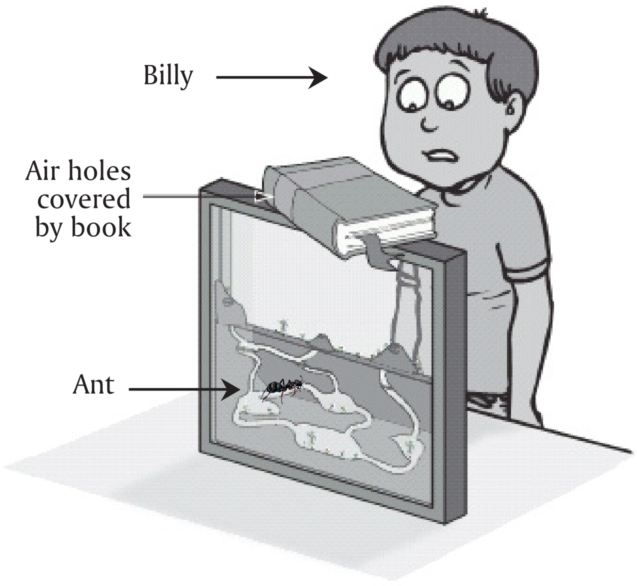


Which of the following statements describes what will happen to the air inside the ant farm as a result of the air holes being covered?

A. The oxygen concentration and the carbon dioxide concentration will both increase.
B. The oxygen concentration and the carbon dioxide concentration will both decrease.
C. The oxygen concentration will decrease and the carbon dioxide concentration will increase.
D. The oxygen concentration will increase and the carbon dioxide concentration will decrease.

Adapted Question 2

Using strategies 1, 2, 6 and 7 from Appendix A



Glossary

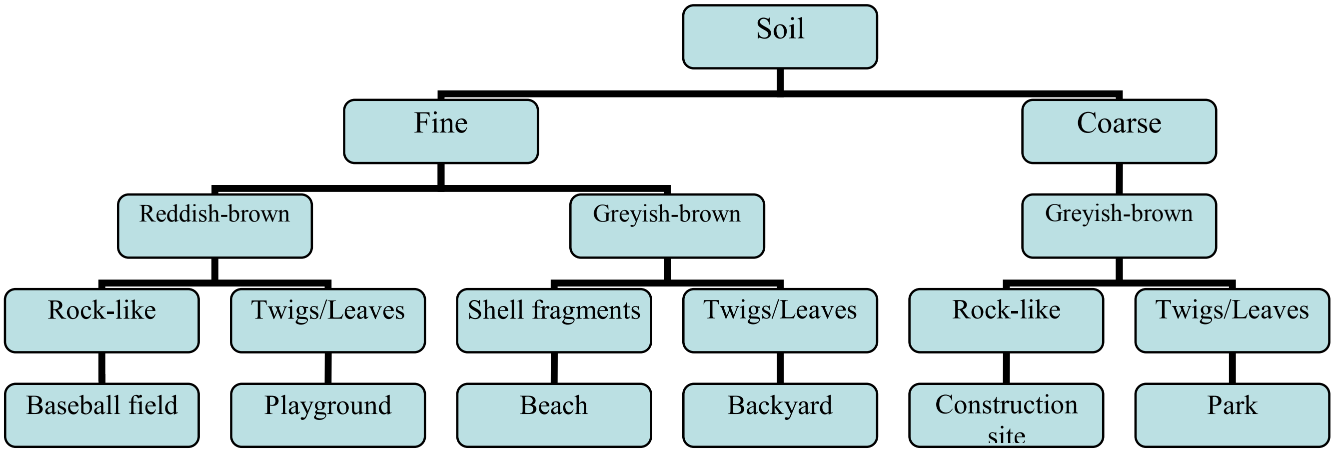
ant. An insect that lives in a colony or group. Ants can be red, black, brown or yellow.
ant farm. A container of ants.
air holes. Holes to let air into the ant farm.

At lunch time, Billy put his book on top of his ant farm. The book covered the air holes. What will happen to the air inside the ant farm? There will be ________________.

A. more carbon dioxide and more oxygen
B. less carbon dioxide and less oxygen
C. more carbon dioxide and less oxygen
D. less carbon dioxide and more oxygen

Question 3

From the released items document for Alberta Education's Grade 6 provincial achievement test for science (2008)

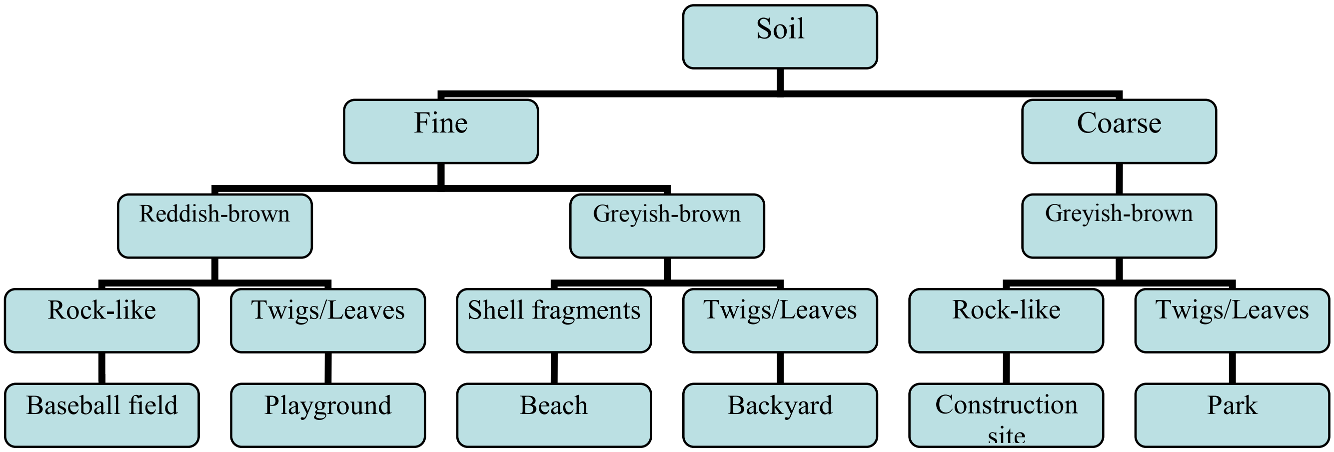


A Science 6 student tracks soil into her house after being outside. The soil is fine with brown, rock-like particles in it. According to the classification chart shown above, where had the student most likely been before entering her house?

A. Beach
B. Playground
C. Baseball field
D. Construction site

Adapted Question 3

Using strategies 1, 2 and 4 from Appendix A



Chris left dirty footprints on the kitchen floor. The footprints had fine, brown, rock-like particles in them.

Look at the chart above. Chris had been at the ________________.

A. Beach
B. Playground
C. Baseball field
D. Construction site

Question 4

From the released items document for Alberta Education's Grade 9 provincial achievement test for science (2006)[4]

The process by which toxins are concentrated as they move up the food chain is called ________________.

A. Pollution
B. Biomagnification
C. Web magnification
D. Biomass stratification

Adapted Question 4

Using strategies 1, 2, 3, 5 and 7 from Appendix A

Large animals in the food chain have more harmful toxins than the smaller animals they eat.

↑ Wolves
Cats
Birds
Mice

This is called ________________

A. Pollution
B. Biomagnification
C. Web magnification
D. Biomass stratification

Question 5

From the released items document for Alberta Education's Grade 9 provincial achievement test for science (2008)[5]

Joe watches television for 6.00 hours (21,600 seconds). The input power rating of his television is 200 W. The electrical energy consumed by any electrical device can be calculated using the following formula.

$E = P \cdot t$
E = energy (in joules)
P = power (in watts)
t = time (in seconds)

The total electrical energy consumed by Joe's television is ________________.

A. 33.3 J
B. 108 J
C. 1.20 kJ
D. 4.32 MJ

Adapted Question 5

Using strategies 1, 2, 7 and 8 in Appendix A

- Joe watches ______ hours of TV, which is ______ seconds of TV.
- His TV uses ______ watts of power.
- Complete the equation using the information above:
  $E = P \times t$
  ______ = ______ × ______
- Joe's TV uses ________________ of energy.

A. 33.3 J
B. 108 J
C. 1.20 kJ
D. 4.32 MJ

Question 6

From the released items document for Alberta Education's Grade 9 provincial achievement test for science (2006)

Use the following information to answer the question below:

White-tailed jackrabbits live on the prairies, are
1 2
consumers, and have fur that changes colour with
3 4
the seasons.

Match each of the underlined words numbered above to the term below that relates to it. Use each number only once.

______	______	______	______
Ecosystem	Niche	Species	Adaptation

Record all four digits of your answer in the numerical-response section on the answer sheet.

Adapted Question 6

Using strategies 1, 2, 3 and 4 from Appendix A

Use the following information to answer the question below:

White-tailed jackrabbits live on the prairies, are
1 2
consumers, and have fur that changes colour with
3 4
the seasons.

On your answer sheet, record the number (1, 2, 3, 4) in column . . .

- A that is an example of an Ecosystem.
- B that is an example of a Niche.
- C that is an example of a Species.
- D that is an example of Adaptation.

A	B	C	D
①	①	①	①
②	②	②	②
③	③	③	③
④	④	④	④

Use each number only once. Then colour the circles that match the numbers.

Notes

1. For examples, see Reiss (2008, 82–83, 160) and Verplaetse and Migliacci (2008, 132).

2. For further examples, see Cleveland (2005) and Alberta's ESL guides to implementation (Alberta Education 2007; Alberta Learning 2002).

3. See http://education.alberta.ca/media/1153254/02%20science%206%20released%202009.pdf (accessed April 3, 2013).

4. Originally retrieved from http://education.alberta.ca/admin/testing/achievement/answerkeys.aspx (no longer available online).

5. See http://education.alberta.ca/media/1153258/02%20science%209%20released%202009.pdf (accessed April 3, 2013).

References

Abedi, J. 2004. "Will You Explain the Question?" *Principal Leadership* 4, no 7 (March): 27–31. Also available at www.nassp.org/portals/0/content/46825.pdf (accessed April 3, 2013).

———. 2006. "Psychometric Issues in the ELL Assessment and Special Education Eligibility." *Teachers College Record* 108, no 11: 2282–303.

———. 2009. "Computer Testing as a Form of Accommodation for English Language Learners." *Educational Assessment* 14, nos 3–4: 195–211.

Abedi, J, and C Lord. 2001. "The Language Factor in Mathematics Tests." *Applied Measurement in Education* 14, no 3: 219–34.

Abedi, J, C Lord, C Hofstetter and E Baker. 2000. "Impact of Accommodation Strategies on English Language Learners' Test Performance." *Educational Measurement: Issues and Practice* 19, no 3 (September): 16–26.

Alberta Education. 2007. *English as a Second Language: Guide to Implementation Kindergarten to Grade 9*. Edmonton, Alta: Alberta Education. Also available at http://education.alberta.ca/media/507659/eslkto9gi.pdf (accessed April 3, 2013).

———. 2010. *Accountability Pillar Fact Sheet*. Edmonton, Alta: Alberta Education. Also available at www.education.alberta.ca/media/1216767/factsheet-accountabilitypillar.pdf (accessed April 3, 2013).

Alberta Learning. 2002. *English as a Second Language: Senior High School Guide to Implementation*. Edmonton, Alta: Alberta Learning. Also available at http://education.alberta.ca/media/653515/esl_shgi.pdf (accessed April 3, 2013).

Bruna, K R, R Vann and M P Escudero. 2007. "What's Language Got to Do with It? A Case Study of Academic Language Instruction in a High School 'English Learner Science' Class." *Journal of English for Academic Purposes* 6, no 1 (January): 36–54.

Carrier, K A. 2005. "Supporting Science Learning Through Science Literacy Objectives for English Language Learners." *Science Activities* 42, no 2: 5–11.

Chamot, A U, and J M O'Malley. 1986. *The CALLA Handbook: Implementing the Cognitive Academic Language Learning Approach.* White Plains, NY: Addison-Wesley.

Cleveland, M. 2005. *Content-Area Graphic Organizers: Language Arts.* Portland, Maine: Walch.

Edmonds, L M. 2009. "Challenges and Solutions for ELLs: Teaching Strategies for English Language Learners' Success in Science." *The Science Teacher* 76, no 3 (March): 30–33.

Fathman, A K, and D T Crowther, eds. 2006. *Science for English Language Learners: K–12 Classroom Strategies.* Arlington, Va: National Science Teachers Association Press.

Herrell, A, and M Jordan. 2008. *50 Strategies for Teaching English Language Learners.* 3rd ed. Columbus, Ohio: Pearson Prentice Hall.

Herrera, S G, K G Murry and R M Cabral. 2007. *Assessment Accommodations for Classroom Teachers of Culturally and Linguistically Diverse Students.* New York: Pearson.

Katz, A, and J K Olson. 2006. "Strategies for Assessing Science and Language Learning." In *Science for English Language Learners: K–12 Classroom Strategies,* ed A K Fathman and D T Crowther, 61–77. Arlington, Va: National Science Teachers Association Press.

Kopriva, R J. 2008. *Improving Testing for English Language Learners.* New York: Routledge.

Kopriva, R J, J E Emick, C P Hipolito-Delgado and C A Cameron. 2007. "Do Proper Accommodation Assignments Make a Difference? Examining the Impact of Improved Decision Making on Scores for English Language Learners." *Educational Measurement: Issues and Practice* 26, no 3 (Fall): 11–20.

Milnes, T, and L Cheng. 2008. "Teachers' Assessment of ESL Students in Mainstream Classes: Challenges, Strategies, and Decision-Making." *TESL Canada Journal* 25, no 2 (Spring): 49–65. Also available at www.teslcanadajournal.ca/index.php/tesl/article/viewFile/129/129 (accessed April 3, 2013).

Reiss, J. 2008. *102 Content Strategies for English Language Learners: Teaching for Academic Success in Grades 3–12.* Columbus, Ohio: Pearson Prentice Hall.

Richards, M R E, and S N Omdal. 2007. "Effects of Tiered Instruction on Academic Performance in a Secondary Science Course." *Journal of Advanced Academics* 18, no 3 (May): 424–53.

Short, D J, M Vogt and J Echevarria. 2011. *The SIOP Model for Teaching Science to English Learners.* Boston: Pearson.

Verplaetse, L S, and N Migliacci. 2008. *Inclusive Pedagogy for English Language Learners: A Handbook of Research-Informed Practices.* Mahwah, NJ: Erlbaum.

Willner, L S, C Rivera and B D Acosta. 2009. "Ensuring Accommodations Used in Content Assessments Are Responsive to English-Language Learners." *The Reading Teacher* 62, no 8 (May): 696–98.

Quantifying Equestrian Show Jumping: A Large Context Problem for Physics Students

Arthur Stinner

Equestrian show jumping has become a popular spectator sport in Canada since the Beijing Olympic Games in 2008. Canada received a gold medal in singles and a silver in team competition. Eric Lamaze and his stallion Hickstead, generally regarded as the best show-jumping horse of his generation, became internationally famous, and Lamaze was ranked first in the world. Unfortunately, three years later Hickstead suddenly died in Verona, Italy, after jumping a clear round. This tragic event plunged the equestrian community into deep mourning.

These events reawakened the love for horses I acquired when working in the forestry industry in British Columbia as a young man. As a physics educator, I naturally became interested in the physics of the jumping motion of these magnificent animals.

I remember a letter written by an irate reader of the British journal *New Scientist* in response to my article “Physics and the Bionic Man” (Stinner 1980). The gentleman argued that my testing the feats claimed by the bionic man, using the laws of physics, spoiled the enjoyment of many devotees of the popular TV series *The Six Million Dollar Man.*

As students of physics, we can always appreciate the aesthetics of phenomena such as rainbows and sunsets, but understanding the physics should enrich our aesthetic appreciation. Similarly, equestrian show jumping can be appreciated on more than one level.

The Background Story

Last September I went to see some jumping events at Spruce Meadows, near Calgary, which is considered the Wimbledon of show jumping. I was especially interested in understanding the kinematics and dynamics of the jumping. I wanted to see if, as in the case of the physics of the bionic man, it was possible to establish a context, embedded in a good storyline that would interest many students.

The central idea behind contextual teaching of physics is that a context that attracts students’ interest and sparks the imagination can be developed in such a way that questions and problems arise from the context naturally, not in a contrived way (as in textbooks). Also, the problems generated have no obvious answer (even to the instructor) and can be solved using basic physics and mathematics. The reader is encouraged to visit my website to see the many large context problems I have developed over the years.[1]

It was easy to get data for the study of the dynamics of the bionic man by simply watching the TV series. It was also easy to show that the feats claimed for him were physically impossible. However, the feats of the show-jumping horses were there for all to see.

Nevertheless, the data for the jumping were not available. I considered taking a high-speed camera and a Doppler shift apparatus to Calgary to measure speeds—but I soon discovered that because of the apparatus required, as well as requiring access to a thoroughbred horse and a rider, this was not a realistic proposition.

My aim was to obtain enough data to describe the kinematics and dynamics of a horse’s jumping over a high fence and a wide water barrier, using basic physics and elementary mathematics suitable for high school physics students. I managed to combine the data from articles on biomechanics with simple observation of jumping on a CBC TV presentation of a Grand Prix event at Spruce Meadows. Using the TV remote control and the pause button, which responded to a time interval of 1/50 s, I was able to estimate the speed, the time of flight and the time taken for a horse's hind legs to "stop" moving just before the jump could be estimated. The results I obtained were reasonably good for both the kinematics and the dynamics of jumping.

Luckily, I had recorded other equestrian competitions. I studied the motion of Eric Lamaze and his new young mare, Derly, in a Grand Prix event in which they placed second. That event—the CN Grand Prix of June 12, 2012—can be found on YouTube. I encourage readers to watch and study Lamaze and his horse.

Moghaddam and Khosravi (2007) were useful in estimating takeoff velocity, height of the centre of gravity (CG) trajectory, time of flight and range of the jump. Meershoek et al (2001) provided data for the forces on the horse's legs on landing. These data were for jumping heights of 1.4 m.

For the kinematics and dynamics of clearing a fence, we need to know the following:

- *The height of the fence.* The height of the fence was 1.6 m, the maximum height permitted for the event.
- *The speed of the horse just before liftoff.* An investigation of the kinematics of horse jumping reports an average approach speed of 3.7 m/s (Moghaddam and Khosravi 2007). I assumed a speed of 4.0 m/s for our case.
- *The angle of elevation of the horse just before takeoff.* The average angle of elevation in Moghaddam and Khosravi (2007) was 40–45°. For our case, this angle was easily found by measurement to be about 40°. In Figure 1, the angle of Derly's body is indeed about 40°.
- *The time of contact between the hind hoofs that is needed for push-off.* This time was estimated by counting the number of pauses required for the hind hoofs to produce liftoff, and was found to be about 0.2 s. This measurement is crucial for determining the forces involved.
- *The time of flight of the horse and rider.* Moghaddam and Khosravi (2007) report an average time of flight of about 0.8 s. Using the pause button, I found that the time it took for the horse to jump the 1.6 m fence was about 0.7 s. This value will be confirmed by kinematic calculations.
- *The total distance from the contact point of takeoff and the landing on the front hoofs.* This distance could be estimated to be about 5.0 m—again to be confirmed by kinematic calculations.

I also needed to know the weight (mass) and height of the horse, as well as the weight of the rider. Derly weighs about 500 kg, and her height is given as 17 hands (1.73 m). With the mass of Lamaze and the saddle, the combined mass is about 570 kg.

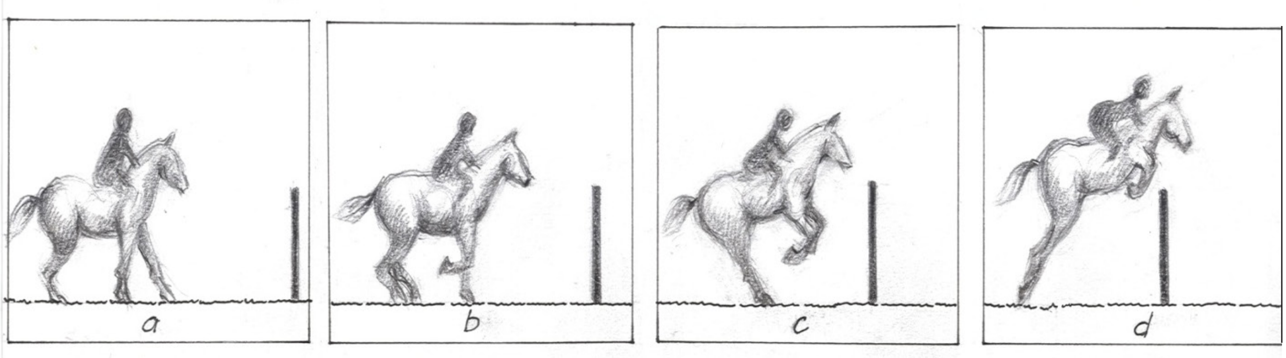
Figure 1

Eric Lamaze and Derly jumping a 1.6 m fence. The takeoff angle is almost exactly 40° from the horizontal, and the distance from the fence to the hoofs is about 2.5 m. The CG of the pair is roughly 20.0 cm along Derly's body, where Eric's right foot is. Photo courtesy of Franz Venhaus.

Jumping Fences

The following descriptions of the approach, takeoff, flight and landing during a jump are adapted from a comprehensive piece by Sheila Schils, a well-known expert in equine rehabilitation, entitled "Biomechanics of Jumping."[2]

The Approach and the Push-Off



The Flight and the Landing

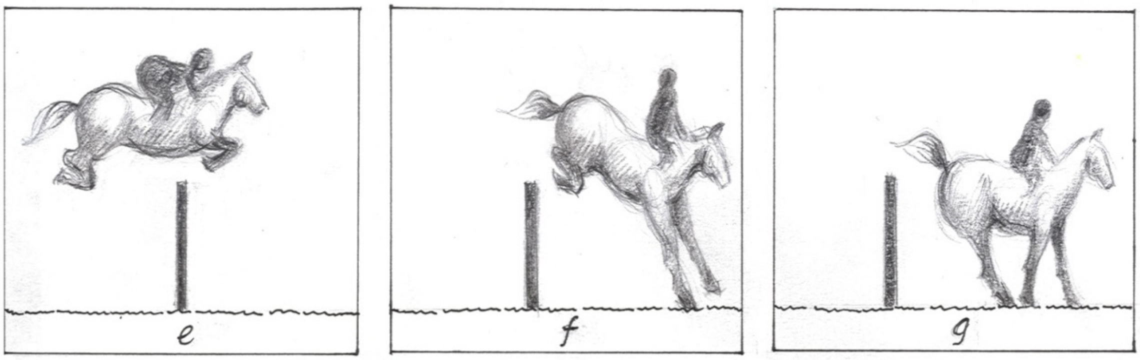


Figure 2

Fence jumping: approach, push-off, flight and landing

Approach

The horse must reach the fence at an even, steady gait (usually a canter motion) so that she can focus on the best spot for takeoff. See Figure 2a.

The horse reaches forward and down with her neck in order to lower the front legs and her CG. The front legs are propped or strutted out in front of the body. This relatively sudden braking action allows momentum to carry the hind legs further under the body of the horse than would otherwise be possible.

Takeoff

See Figures 2b, 2c and 2d.

As she finishes the last whole stride before the jump, the horse begins to shift her weight backward by raising her head, shortening her neck and lifting her shoulders.

Her neck continues to shorten to help move the weight backward. This also helps to stop the normal forward movement of the canter.

As the weight moves backward, the hind legs compress or coil. With the maximum amount of flexion in the hind joints, the horse can then create the maximum push against the ground to propel herself up and forward. The horse has the most effective takeoff when her hip joint is placed vertically above the hoof.

Flight

See Figures 2d, 2e and 2f.

The horse's hind legs reach maximum extension after they leave the ground, and her front legs are curled tight against her body.

Her knees lift and bend to curl the legs up, the tighter the better, to reduce the chance of her hitting the fence with her front legs. To bend her knees and lift her forehand (the front part of the horse's body), the scapula (shoulder) rotates upward and forward. During the flight, the CG follows an approximate parabolic trajectory.

Landing

See Figures 2f and 2g.

To slow the forward momentum and reduce the force of impact, the horse swings her neck and head up as her forelegs reach toward the ground.

The horse's nonleading front leg lands first. When her leading front leg lands, both legs push against the ground in an upward and backward direction. The hindquarters rotate underneath the trunk and reach toward the ground as the forehand moves forward and out of the way of the hindquarters.

Jumping Fences: Physical Principles

Approach and Takeoff

I am referring, for analysis, to one of the 1.6 m fences used in the Grand Prix. Derly approached this high fence with a speed of about 6.0 m/s. Her speed was reduced by a shorter stride to about 4.0 m/s just before she anchored her hind legs. We assume that the horizontal speed of 4.0 m/s does not change significantly during the 0.2 s push-off.

In Figure 1, Derly's front legs are lifted and her hind legs stop moving for about 0.2 s. This is called the stance phase. The front legs are coiled so that the body of the horse, with reference to the horizontal, can be as high as 45°, just before push-off. The hind legs uncoil, and at the point of leaving the ground, the angle for the trajectory is about 40°. During this stance phase, the body moves about 0.8 m (4.0 m/s × 0.2 s).

At the moment of takeoff, Derly's CG is about 20.0 cm along the line of her body, in front of Lamaze's right foot.

Knowing the angle at takeoff and the horizontal velocity, we can easily determine the instantaneous vertical velocity at the beginning, the height, the range and the time of flight for the trajectory.

The Kinematics of the Jump

See Figure 3.

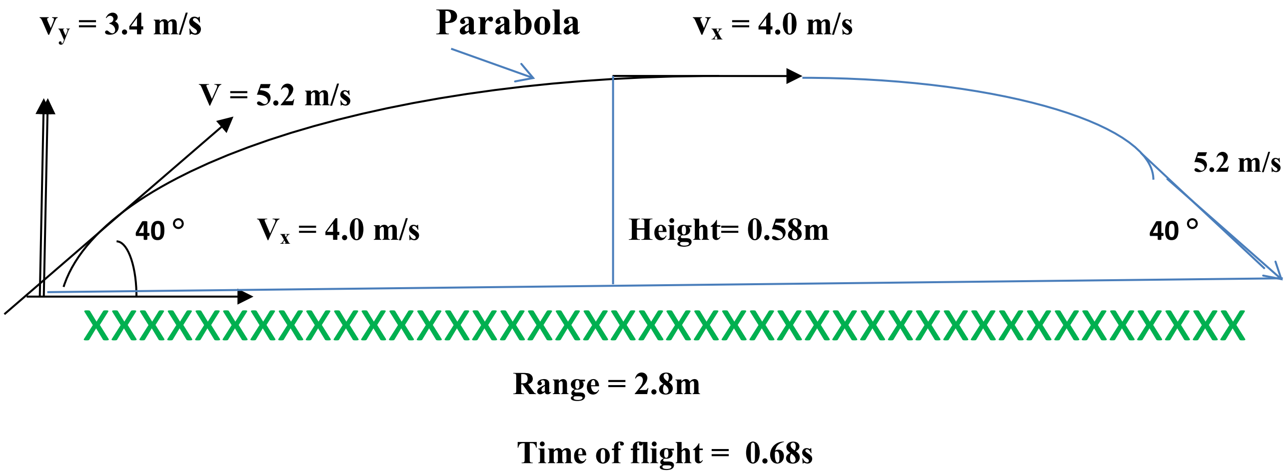


Figure 3

The motion of the CG of horse and rider over a 1.6 m fence

Derly pushes off when the angle to the horizontal is about 40°, and the CG at this moment happens to be at about the same height as the fence. The horizontal velocity (v_x) is constant at about 4.0 m/s. (We will assume that the value of g, the gravitational attraction, is $g = 10.0 \text{ m/s}^2$.)

The vertical velocity (v_y) at the moment of liftoff is given by

$$v_y = v_x \tan 40°. \tag{1}$$

Therefore,

$$v_y = 4.0 \tan 40° = 3.4 \text{ m/s}$$

and the time t to reach height h is obtained from

$$v_y = gt \tag{2}$$

or

$$t = v_y/g = 3.4/10.0 = 0.34 \text{ s}.$$

The total time for the trajectory is $2t$, or 0.68 s.

Since

$$v_y^{\,2} = 2gh, \tag{3}$$

the height reached by the CG is

$$h = 3.4^2/20.0 = 0.58 \text{ m}.$$

The total height from the ground to the CG is

$$1.60 + 0.58 = 2.18 \text{ m}.$$

The range R of the CG is given by

$$R_{\text{CG}} = 2v_x t \tag{4}$$

or

$$R = 4.0 \times 0.68 = 2.72 \text{ m}.$$

The tangential velocity v_T at the point of liftoff is

$$v_T = (v_x^{\,2} + v_y^{\,2})^{1/2}$$

or

$$v_T = (4.0^2 + 3.4^2)^{1/2} = 5.2 \text{ m/s}.$$

Remember that the distance from the spot where the hind leg hoofs take off and the horizontal distance to the CG (that is, the start of the trajectory) is about 1.0 m. If the jump is perfectly symmetrical (and it seldom is), the distance from the base of the fence to the point of contact, in this case, is about 2.72 m. The total range R is

$$R = 2.72 + 2.0 = 4.8 \text{ m}.$$

It should be noted that the location of Derly's CG (see Figure 1) does change somewhat during the flight as the horse's body configuration changes (due to the movement of the neck and the leg during the flight). Therefore, the trajectory is only an approximate parabola, as indicated in Figure 4.

The Dynamics of the Jump

The motion during the push-off stage that takes about 0.2 s is fairly complicated. Looking at Figure 2, it is clear that the force F produced by the hind legs is almost vertical. However, it misses the CG by a small distance d, which increases during this short time of contact. At the start of the push, Derly's body is along an elevation of about 45° (see Figure 5). As the hind legs push forward (remember that the hoofs are

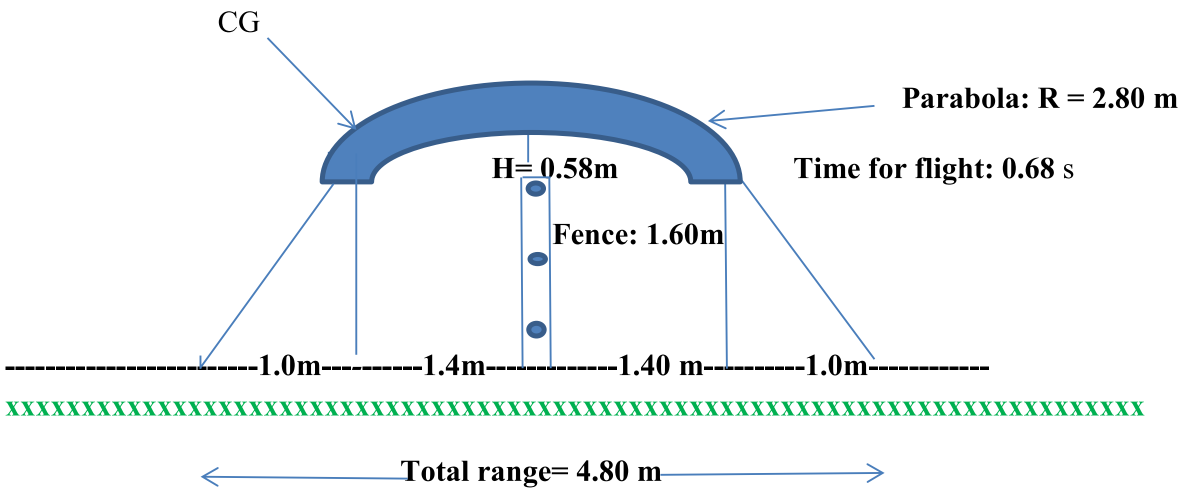
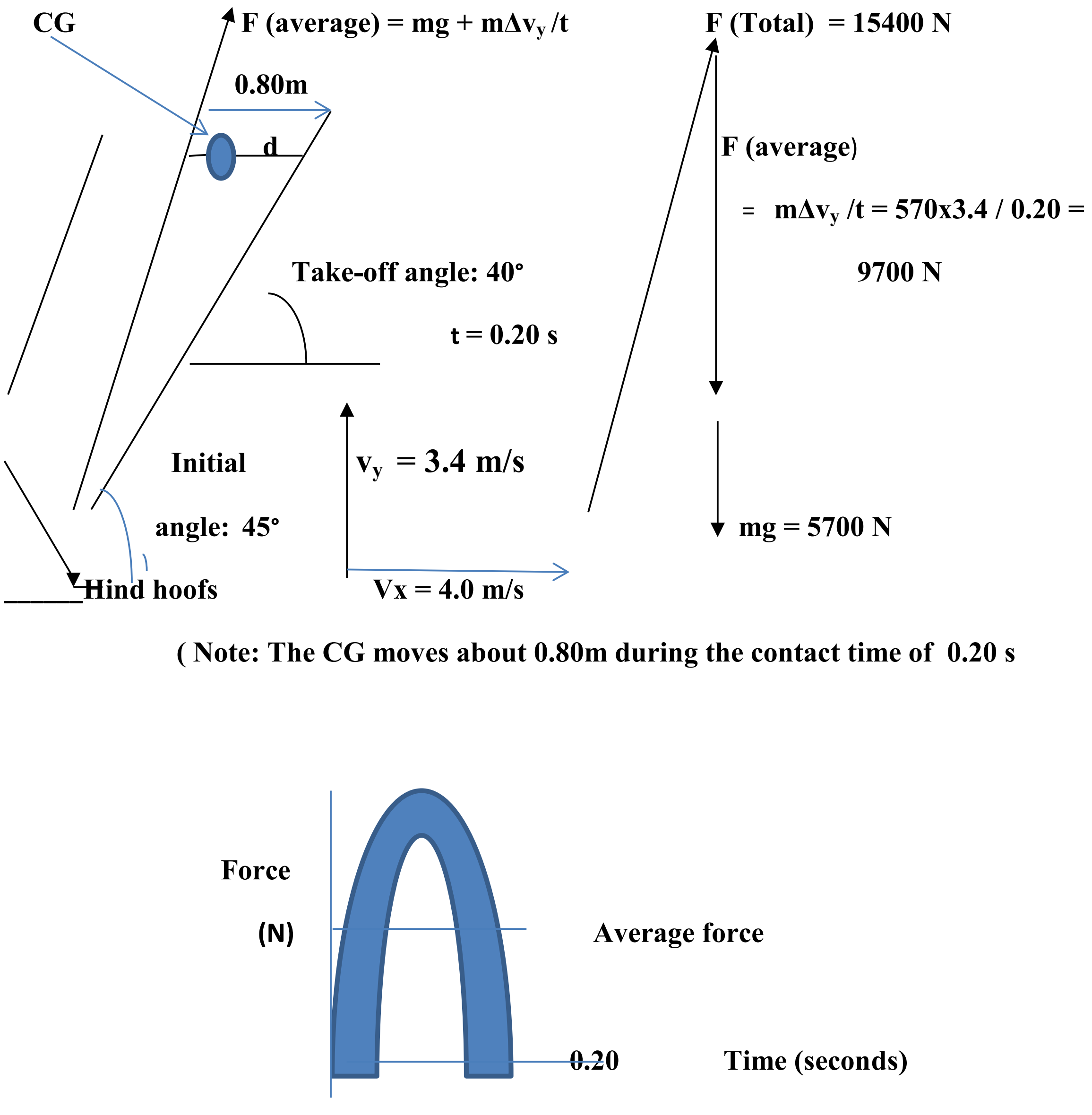


Figure 4

The kinematics of jumping a 1.6 m fence

stationary during this brief period), the body moves about 0.8 m forward. The product of *dF* is a torque, which causes Derly to rotate clockwise for about 0.2 s. When the hoofs leave the ground, the CG has moved about 0.8 m horizontally and Derly is moving with an initial vertical velocity of 3.4 m/s and a constant horizontal velocity of 4.0 m/s—essentially along a parabolic trajectory. The resultant initial velocity, then, must be 5.2 m/s, as shown earlier.

When contact with the ground has ended, the direction of the body of the horse is about 40° with the horizontal.



(Note: The CG moves about 0.80m during the contact time of 0.20 s

* * *

Figure 5

Forces acting during takeoff (0.2 s)

The impulse, $F\Delta t$, is equal to the rate of change of momentum, or $F\Delta t = m\Delta v$, where F is an average force.

We can estimate the average force acting on the legs to produce the liftoff by finding the vector sum of the vertical and horizontal force during contact. In addition, we assume that, for the liftoff, most of the force acts in the vertical direction and we can ignore the horizontal force. The combined mass of Derly, Lamaze and the saddle is about 570 kg.

The average push force during the 0.2 s can be obtained by using the relationship between impulse and change of momentum:

$$F\Delta t = m\Delta v.$$

Therefore,

$$F = m\Delta v/\Delta t.$$

The vertical force necessary to propel the CG of the horse to the height h is

$$F_y = mg + m\Delta v/\Delta t$$
$$\Delta v/\Delta t = 3.4/0.2 = 17.0.$$

Therefore,

$$F_y = m(g + \Delta v/\Delta t) = 570(10.0 + 17.0) = 15{,}400 \text{ N}.$$

This is a large average force that acts during the 0.2 s contact. The force varies during this short time and peaks at perhaps 19,000 N, at about $t = 0.1$ s, as shown in Figure 5. Therefore, the force calculated is an average force.

The force is equivalent to about 15,000 N, or a 1,500 kg-force, or about 3,300 lb. Therefore, each leg must be able to support a force of about 750 kg-force in a symmetric case.

The total energy expended by the hind legs for our jump is given by

$$E = mgh.$$

Therefore, the energy produced for the jump is

$$E = 570 \times 10 \times 0.58 = 3{,}306 \text{ J}.$$

It is interesting to calculate the average power generated during this jump. Since about 3,300 J of energy is produced by the push-off in 0.2 s, the power is 3,300/0.2 = 16,500 W, or about 22 HP.

About 7.0 W/kg is produced by each hind leg when jumping a fence 1.4 m high.

The average force on landing that acts on the front legs, however, is a little larger, because the horse typically slows down to about 3.0 m/s during the 0.2 s contact. See Figure 6.

The vertical force F_y is, as before, about 15,400 N, but we also have a horizontal force acting because of the reduction of the velocity by about 1.0 m/s. The average horizontal force is

$$F_x = m\Delta v/\Delta t = 570 \times 1.0/0.2 = 2{,}900 \text{ N}.$$

The total force is

$$F = (F_x^2 + F_y^2)^{1/2}$$

or

$$F = (2{,}900^2 + 15{,}400^2)^{1/2} = 16{,}000 \text{ N}.$$

Is this large force reasonable? The force measurements for jumping over a 1.4 m fence, as reported in Meershoek et al (2001), are given as an average of 14 kN.

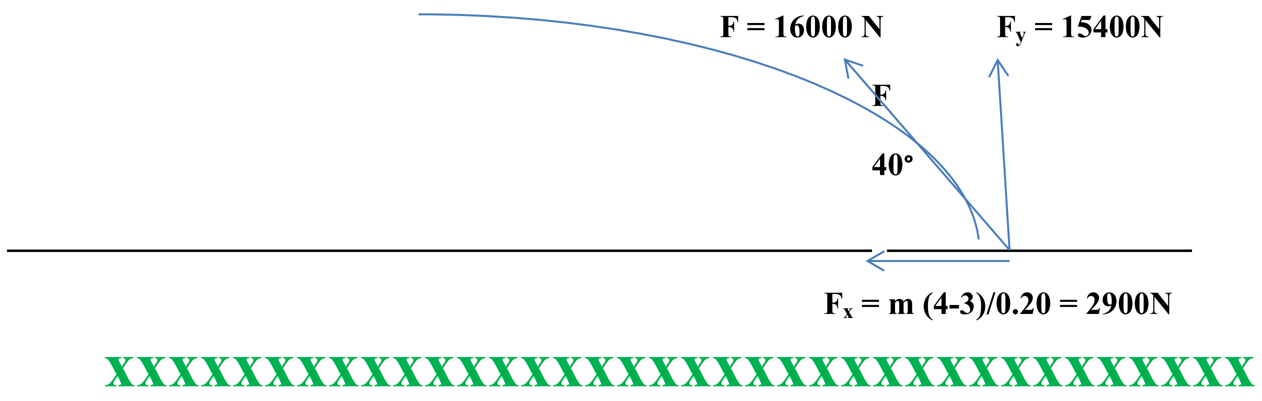


Figure 6
Forces acting on landing

The Ideal Liftoff Distance

The kinematics of elementary trajectory motion require that the CG of the horse in our case clear the fence by a height of 0.58 m in 0.68 s. If we want to maintain this height, the time of the trajectory does not change with the push-off distance (see Figure 7). This is a well-known discrepant event, and it always astonishes students when they see a demonstration, using balls rolling off a table at different speeds.

We can assume that the ideal liftoff distance from this fence is about 1.4 m (that is, the distance from the CG to the fence at the moment of liftoff). The hind hoofs must be anchored at a distance of about 2.5 m from the fence. The angle of elevation of the horse at the beginning of the push will be about 45°, and at the moment of liftoff it will decrease to about 40°. The clockwise rotation of the horse's body during this brief 0.15 s contact time is due to the torque produced by the upward push of the legs, the direction of this force missing the CG by a small amount.

For example, if the distance of the CG on takeoff is only 0.5 m closer to the fence, then the angle at takeoff will be over 50°. On the other hand, if the horse jumps from a distance 1.0 m behind the optimum distance of about 2.4 m, the angle will be about 30°, but the horizontal velocity will have to be 7.2 m/s. Since the horse generally slows down by about 2.0 m/s just before the takeoff stance, the approach velocity would have to be at least 9.0 m/s. This velocity usually requires galloping and results in lessening the horse's ability to assume a symmetric stance for takeoff.

In addition, the forces acting on the front legs will be a little larger, because the horse typically reduces the landing speed to about 3.0 m/s. That means that there is a greater horizontal force than in the optimal case:

$$F_x = m\Delta v/\Delta t = 570(7.2 - 3.0)/0.20 = 12{,}000\ \text{N}.$$

The vertical force, as for the hind legs, is 15,400 N.

The total force acting on the front legs then is

$$F = (F_x^{\,2} + F_y^{\,2})^{1/2} = (12{,}000^2 + 15{,}400^2)^{1/2} = 20{,}000\ \text{N}.$$

This is a considerably larger force acting on the front legs than when jumping the shorter trajectory.

Therefore, if Lamaze chooses the longer jump to gain advantage in time, he risks his horse having to encounter greater retarding forces, especially on landing.

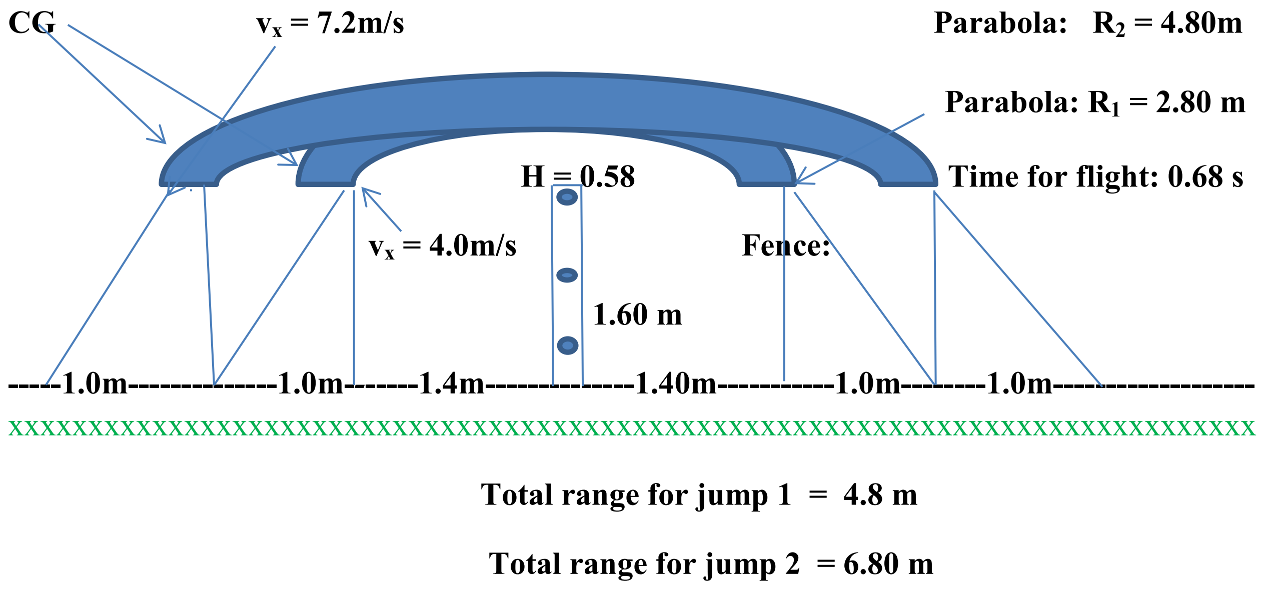


Figure 7
Comparing the kinematics of two jumps for the same height above the fence

Finally, it should be mentioned that just as in the case of the takeoff force acting behind the CG of the horse, producing a clockwise rotation, the contact force produced by the front legs on landing acts in front of the CG and produces a counter-clockwise rotation. Indeed, if the angle of descent is large enough, the horse will rotate clockwise, which results in a dangerous somersault, with a potential of severe injury to both rider and horse.

Water Jumping

If equestrian jumping is like jumping hurdles, then water jumping is similar to the long jump. Figure 8 shows an ideal water jump.

The width of the jump at the Grand Prix at Spruce Meadows was 4.2 m. So Lamaze and Derly had to make sure the jump was at least 5.0 m long (see Figure 9). The angle of elevation at takeoff was about 25° and the approach speed about 7.5 m/s, because for a range of trajectory to be 5.0 m, at an angle of 25°, the horizontal velocity must be 7.5 m/s. Following the same reasoning as before and using equations 1, 2, 3 and 4,

$$5.0 = v_x t = 7.5t.$$

Therefore, $t = 0.7$ s.

Since $\tan 25° = v_y/v_x$, $v_y = 3.5$ m/s, the height h of the trajectory is

$$h = v_y^2/20 = 0.61 \text{ m}.$$

The contact time for the takeoff is also about 0.2 s and, therefore, the vertical force necessary for the trajectory is given by

$$F_y = mg + m(3.5/0.2) = 570(10.0 + 17.5) = 15{,}600 \text{ N},$$

very much the same as for the 1.6 m fence.

On landing, the vertical force F_y, as for the hind legs on takeoff, is about 15,600 N. As before, the horse is reducing her speed, this time to about 5.0 m/s, from 7.5 m/s. Therefore, the horizontal force is

$$F_x = 570(2.5/0.2) = 7{,}100 \text{ N}.$$

The total force then is

$$F = (15{,}600^2 + 7{,}100^2)^{1/2} = 17{,}000 \text{ N},$$

a little larger than the force required for the fence jumping.

These large forces acting on the horses, even if only for a short time, are stressful for them. Riders are concerned about their horses and make sure that they are healthy, both physically and emotionally. Horses are examined by veterinarians before each competition. Serious accidents in Grand Prix jumping, unlike in steeple chasing or racing, are rare.

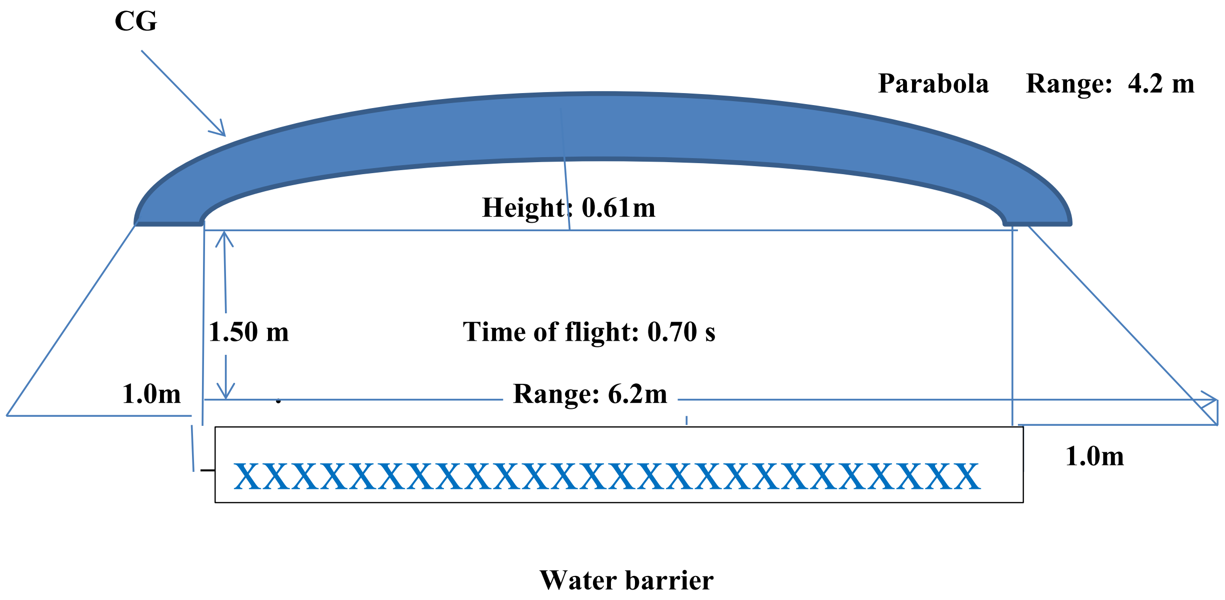


Figure 8
Kinematics of jumping the water barrier

Comparison with Hurdles and the Long Jump

The world record for the 400 m hurdles for men is about 47.0 s. That means that the average speed of the athlete in this event is about 8.5 m/s. The average speed at the Spruce Meadows International Grand Prix ring, over a distance of 550 m and with a restricted time of 84.0 s, is about 6.7 m/s. The maximum speed of a human sprinter today is about 10.5 m/s (38.0 km/h), but show-jumping horses can run as fast as 14.0–15.0 m/s (50.0 km/h). There were two places where the horse could gallop between barriers, notably before the water jump, where Lamaze seems to have allowed a speed of over 10.0 m/s for Derly over a distance of about 25.0 m.

The kinematics and dynamics of jumping over a hurdle about 1.0 m high are similar to those of the show jumper clearing a high fence. The approach speed for the hurdle, however, is much higher—about 10.0 m/s. The takeoff angle is 70–80°, almost twice as steep as that of the horse jumping a high fence. Students can work out the force required for an athlete, with his centre of gravity about the height of the hurdle and a mass of 70 kg, to clear the hurdle at a height of about 30.0 cm.

The kinematics and dynamics of the long jump are also similar to the jump of a horse over a water barrier. Olympic long jumpers typically jump over 8.0 m. They approach the liftoff point with a speed between 9.0 and 10.0 m/s. The optimum angle of elevation is about 20°. Again, students could study the kinematics and dynamics of the long jump of a world-class athlete for comparison.

Conclusion

The data used in these calculations would not be sufficient for an article in a technical research journal on biomechanics. However, our results look reasonable and the physics we used is solid, so that improved data could easily be applied. I hope that after studying the physics of equestrian show jumping, students will get more enjoyment out of watching a Grand Prix.

I hope to send a copy of this article to Eric Lamaze, and perhaps after reading it, he will invite me to Spruce Meadows to make good measurements, using Derly as our subject.[3] I would be especially interested to find out how many of these principles of kinematics and dynamics Lamaze consciously applies when judging his speed and position for jumping. However, perhaps a study of the physics of his craft would compromise his smooth and seamless riding.

Figure 9
Eric Lamaze and Derly jumping a water barrier

Notes

I would like to thank my wife, Ann, for the sketches in Figure 2 and her helpful suggestions for improving the article.

1. http://home.cc.umanitoba.ca/~stinner/teacherresources.html

2. See www.equinew.com/jumping.htm (accessed May 7, 2013).

3. Unfortunately, since the time of writing, Eric Lamaze has sold Derly and is concentrating on developing his young stallion Wang Chung M2S. He has had some good wins lately. We wish them a successful future.

References

Meershoek, L S, H C Schamhardt, L Roepstorff and C Johnston. 2001. "Forelimb Tendon Loading During Jump Landings and the Influence of Fence Height." *Equine Veterinary Journal* 33, no S33 (April): 6–10.

Moghaddam, M S, and N Khosravi. 2007. "A New Simple Biomechanical Method for Investigating Horses Jumping Kinematics." In *XXV International Symposium on Biomechanics in Sports 2007*, *Ouro Preto—Brazil,* 579–82. Also available at https://ojs.ub.uni-konstanz.de/cpa/article/viewFile/549/488 (accessed May 7, 2013).

Stinner, A O. 1980. "Physics and the Bionic Man." *The Physics Teacher* 18, no 5 (May): 358–61. (Reprinted in *New Scientist,* December 18–25, 1980, 806–09.)

A Physicist Does Biology

Frank Weichman

Many decades ago I got involved with a colleague in the University of Alberta's entomology department, George Evans, who wanted to study certain beetles that flock to forest fires, where they lay their eggs in the warm ashes.

Dr Evans asked me to help him find equipment to explore the wavelength sensitivity of the beetles. I was drawn into that part of the research because I was involved with investigating radiation absorbed and emitted by semiconductors in the same near-infrared region of the spectrum.

The experimental results of the beetle study were published in the journals *Nature* (Evans 1964) and *Ecology* (Evans 1966).

A few years later, Dr Evans asked me to check his calculations of the intensity of the source (the forest fires) and compare it with the sensitivity of the sensors on the beetle.

Some 40 years after the original study, there was a revived interest in the beetle because of perceived military applications for man-made detectors based on beetle sensors.[1] After all, it was said that a beetle could detect forest fires from as far as 100 km away. Dr Evans was skeptical about this detection radius, in part because the sensors were along the side of the beetle's body and partly blocked by the beetle's wings while in flight. You would think that if a beetle were aiming to get to a fire, the sensors would have the target in view. In addition, he did not think that an area with a radius of 100 km would be required in order to attract the numbers of beetles that show up to breed in the warm ashes. It is a common species, with sufficient numbers of beetles in much smaller areas. Finally, he wondered if the sensors had a purpose different from detecting forest fires. What evolutionary purpose might they serve?

A side issue, particularly for Dr Evans's colleagues in entomology at the U of A, was the matter of scientific priority. Recent articles on the topic had not given due credit to Dr Evans for his work on the infrared sensitivity of beetles.[2]

Join me, then, for a biophysics exploration of the *Melanophila acuminata* (De Geer) beetle and forest fires. I will also tell you about the sensitivity of man-made detectors in the same wavelength range and the implications.

The Beetle

The *Melanophila acuminata* (De Geer) beetle has infrared receptors along the sides of its body, behind its wings. To pin down the sensitivity of these organs, Dr Evans bought a sodium chloride prism spectrometer, which we calibrated in terms of wavelength and power output. The infrared output of the spectrometer was aimed at the organs of a gently confined beetle. Beetles twitch when they sense radiation. By varying the output wavelength and watching for twitching, Dr Evans determined that the wavelength range of sensitivity is in the 3.0 μm spectral range (that is, an infrared wavelength roughly five times longer than the wavelength the eye perceives as yellow). At each output wavelength of the spectrometer, he could measure and change the intensity of the radiation. He found the beetle's threshold of reaction to an infrared radiation pulse to be 6.0×10^{-5} W/cm^2.

The actual receptors of the beetle are individual cavities about the size of the wavelength they detect. They are clustered in organs, with one organ on each side of the beetle's body. The organs are roughly 0.1 mm across. The detailed morphology is described in Evans (1964, 1966).

Forest Fires

If we want to determine the distance at which the infrared output of a forest fire might be detected by the infrared sensors of the beetle, the input for our calculation must start with the temperature of the fire and the size of the source.

Here are some relevant data. Intense forest fires can burn trees from the ground up to about 10 m in height. The measured temperature of a forest fire is in the range of 600°C, and the emissivity associated with such a fire is $\varepsilon = 0.95$.

In translating the biology into physics, some questions arise. I have posed these questions as a series of problems a teacher might set. The answer to each problem follows, and the work involved to get to the answer is detailed in the appendix.

Problem 1

1a

For the given temperature of the fire (600°C), determine the peak wavelength of the emitted black-body radiation.

Answer

The peak wavelength (λ) is obtained by using Wien's displacement law: $\lambda T = 2.9 \times 10^{-3}$ mK, where T is the absolute temperature of the black body. The result (as shown in the appendix) is 3.2 μm, close to the measured wavelength sensitivity of the beetle's sensors.

1b

Physicists start with oversimplified models. Suppose that the fire is a spherical source 10.0 m in diameter. Estimate the total intensity of the black-body radiation from the fire (in watts per square centimetre) at the location of a beetle 1.0 km from the fire. (I am using centimetres here because that is in line with the size of the beetle.)

Answer

Radiation is emitted according to the Boltzmann equation: $P = \varepsilon \sigma T^4 A$. As shown in the appendix, the resulting intensity at 1.0 km is 8.9×10^{-5} W/cm^2.

1c

Assume that the infrared sensors of the beetle pick up all the incident radiation from 2.9 μm to 3.1 μm. Estimate the intensity of the radiation from the fire in this wavelength range (in watts per square centimetre) for a beetle 1.0 km from the fire. Is that intensity within the infrared range to which the beetle has been shown to react (6.0×10^{-5} W/cm^2)?

Answer

For this problem, we have to use the wavelength dependence of Planck's radiation law,

$$P(\lambda)\Delta\lambda = \frac{2\pi c^2 h}{\lambda^5}\frac{1}{e^{hc/\lambda kT}-1}\Delta\lambda$$

which will show that the beetle is exposed to radiation at an intensity of $1.5 \,\Xi\, 10^3$ W/μ^2/4 $\times 10^4 = 0.038$ W/m^2 = 3.8×10^{-6} W/cm^2.

That is quite a bit less than the total radiation calculated for the complete spectrum in 1a, as it should be. But it is also an order of magnitude less than the measured sensitivity of the beetle at 6.0×10^{-5} W/cm^2. A beetle should not be able to see a single-tree fire from that far away.

Up pops another question. The sun radiates in the infrared region just as it does in the visible. What is that background intensity? To what extent might it mask the radiation from the forest fire? We, therefore, have to ask for the level of radiation from the sun on the countryside in and around a 3.0 μm range on a clear day. Problem 2 shows how to get that estimate.

Problem 2

The surface of the sun emits radiation that closely approximates a black body at 5,762 K. The effective radius of the sun as a black body is 6.96×10^8 m, and the distance from the centre of the sun to the earth is 1.5×10^{11} m.

2a

Calculate the total intensity of the total black-body radiation from the sun (in watts per square metre) at the surface of the earth.

Answer

Calculation based on $P = \sigma T^4 A$ will show the intensity of the radiation from the sun at the surface of the earth to be 1,353 W/m^2 = 0.1353 W/cm^2. This value of the radiation intensity is known as the solar constant.

2b

Calculate the intensity of the radiation from the sun on the surface of the earth in the wavelength range from 2.9 to 3.1 μm (in watts per square metre and watts per square centimetre).

Answer

Here we have to use Planck's radiation law again:

$$P(\lambda)\Delta\lambda = \frac{2\pi c^2 h}{\lambda^5}\frac{1}{e^{hc/\lambda kT}-1}\Delta\lambda$$

At the surface of the earth, the radiation will result in an intensity of 5.19 W/m^2 in that wavelength range. If the surface of the countryside were a perfect reflector in the 3.0 μm range, it would be that bright in all directions.

Remember that we have calculated that the forest fire emits radiation at a rate of $1.5 \Xi 10^3$ W/μ^2, close to 300 times the background of the radiation the sun spreads over the area. That would make the forest fire stick out as a bright source if the eye could focus on a source in that wavelength range. But the beetle cannot direct its field of infrared detection. Whatever is detected is averaged over a wide angle of view. To get some handle on it, if each organ on the beetle covers all angles to one side, the combined field of view will cover an area of $4\pi r^2$ at a distance of r and will average out the intensities over that area.

Evans and Kuster (1980) measured the field of view of the organs. They concluded that out of a possible $4\pi = 12.57$ steradians (the total sphere), the receptors on the two sides together can cover 5.80 steradians. But each side by itself covers only 0.42 steradians at full sensitivity (that is, where all the receptors in the organ on that side are exposed to radiation from the same source at the same time).

So, we have a discrimination problem with regard to what the beetle needs to detect against the background of solar infrared radiation. Suppose the beetle is at the centre of a sphere, radius R. How much radiation will it be exposed to? Let each point of the inside of the sphere radiate an amount I for a total radiation of $4\pi R^2 I$ leaving the (inner) surface of the sphere. The beetle is a distance R away, reducing the intensity at the location of the beetle by $1/R^2$ to $4\pi^2 I$, independent of the distance from source to beetle. If the organ of the beetle can pick up the radiation only from an angle of 0.42 steradians, it receives this background radiation at $(0.42/4\pi)4\pi^2 I = 0.42I$ W/m^2. Earlier we calculated $I = 5.19$ W/m^2, which implies that the beetle's infrared sensing organ is exposed to $0.42(5.19) = 2.2$ W/m^2 from the solar background.

We started our forest fire calculations with a minimal fire of 5.0 m radius at a distance of 1.0 km. In other words, a hot sphere of $4\pi(5.0)^2$ m^2 surface area, emitting at an intensity of $1.5 \Xi 10^3$ W/μ^2 but reduced to $1.5 \Xi 10^3$ W/μ^2/$1{,}000^2 = 1.5 \Xi 10^{-3}$ W/μ^2 at the location of the beetle. This radiation intensity is a factor of over a thousand less than the solar background. If the organ could focus its angular coverage from 0.42 steradians to a smaller angle (say, by a factor of a hundred), the beetle would have a chance to detect the fire against the background radiation. That still does not solve the problem of the beetle's lack of overall sensitivity at 6.0×10^{-5} W/cm$^2 = 0.6$ Wμ^2, as measured by Evans.

Does that imply that beetles have to search for considerably bigger fires and do so at night?

One more source of infrared radiation has so far been neglected. Earth itself is a warm object, which radiates like any other black body. Its temperature (depending on the weather) is about 20°C; for the sake of simplicity, let's call it 300 K. How much radiation from this source will the beetle be immersed in? Follow the previous examples (say, the radiation from the sun in the 3.0 μm range) and you will find that the surrounding countryside emits 3.0×10^{-2} W/m^2—tiny compared with the infrared component of the sunshine at the previously calculated 5.19 W/m^2. Also, keep in mind the limited angle over which the sensors receive this particular radiation—the 0.42 steradians.

Next, we will compare the sensitivity the beetle requires in order to find forest fires with the most modern human technology.

Human Technology

One type of radiation detector is a quantum detector. In biology, it senses radiation as individual incident photons causing chemical changes in individual molecules, which in turn trigger a signal in the nervous system of the biological entity.

The eye works on this principle. The dark-adapted eye at maximum sensitivity requires only one photon to twist a molecule in a receptor. To reduce error signals, the first signal is sent on when confirmed by a second photon twisting a nearby molecule within a short time frame.

In condensed matter physics, an incoming photon can eject an electron from a surface—the photoelectric effect. The loose electron is easy to detect. There is a minimum in the photon energy, the work function, which triggers the electron emission. In semiconductors, a somewhat lower photon energy is enough to excite an electron to the conduction band. That is the basis for the CCDs (charge-coupled devices) now used as sensors in cameras.

Modern technology now routinely makes use of close to single incident photon sensitivity in the visible and near-infrared wavelength range. As you can imagine, high-energy photons are easier to detect than low-energy photons. The old Geiger counters allowed us to detect individual gamma ray photons with thousands of electron volt energies apiece. The photoelectric effect as applied to the right kind of surface has a high probability of detecting a single photon with an energy of 1 eV or more. Our dark-adapted eyes are single-photon detectors for the 2.0–3.0 eV energy range.

The beetle in this story is tuned to look for photons of about one-third of an electron volt. Is that a range for single-photon counting? It depends—not because single-photon detectors cannot be made for that wavelength range but, rather, because there are too many stray photons around in the 3.0 μm range emitted from any and all surfaces, including the sun (as we have seen). You can use the Planck expression for a surface at 300 K, and you will note that even such a room temperature surface emits a small but noticeable 3.0 μm radiation. To be useful, practical single-photon detectors for this wavelength range are cooled with dry ice or liquid nitrogen and are carefully shielded from anything but the intended source. Not quite the way beetles are constructed.

So, what other types of sensor are there, for bugs or otherwise, if quantum effects are impractical in the 3.0 μm range? You have to construct a device that measures the energy of the radiation delivered to the detector. How? In practice, the radiation is directed to the black surface of a thin metal foil, and the absorbed energy is detected as a minute increase in the temperature of that foil. If the surface is truly black, the ideal absorber, the device will be equally sensitive to all incident wavelengths. The response of the instrument will just be a question of our ability to measure the increase in the temperature of the foil.

A thermopile is one variant of such a detector. It usually consists of two identical foils, each with fine thermocouples to sense the temperature difference between them. One foil is exposed to the radiation that is to be detected; the other foil is shielded from that radiation. The thermocouples convert the minute temperature difference between the foils into an electrical signal (the thermocouple EMF). Very roughly, such an instrument can distinguish differences in radiation levels of 10^{-9} W/cm^2 of surface area (Strong 1956). Practical foils are up to 1.0 cm^2 in area and a few micrometres thick. Smaller areas work, too, but are more subject to background noise fluctuations. The sensing area of the beetles, as we have mentioned, is but 0.1 mm to a side, and therefore subject to high random fluctuations as compared with human technology.

Other heat-sensitive radiation detectors use changes in shape or pressure due to the heat absorbed by the receiving foil. The ultimate sensitivity remains close to the same. The type of detector chosen is more a question of manufacturing cost or the skill of a scientific artisan to get the highest sensitivity detector. The output of lasers is also often measured with this type of detector, in this case a rugged variant because of the high intensity (watts or even kilowatts) of the laser.

Note that thermal detectors cannot discriminate between the wavelengths of the incoming radiation. In contrast, the single-photon radiation detectors have an energy threshold. The photon energy must be large enough to trigger an electronic reaction.

Biology

Back to *Melanophila acuminata.* Assume the insect is not a photon detector but, rather, it detects the heat of the source at a sensitivity equal to the best human instruments, at 10^{-9} W/cm^2 of surface area. How far does that permit the detection of forest fires in the wavelength range in which the infrared sensors of the beetle operate?

We started our calculations based on a forest fire of barely a single tree: a spherical source of 5.0 m radius. We showed that at a distance of 1.0 km, the intensity of radiation in the 3.0 μm wavelength range is 38×10^{-3} W/m^2 = 3.8×10^{-6} W/cm^2. At 100.0 km from this fire, the beetle is bathed in 3.8×10^{-10} W/cm^2, which makes it dubious that the beetle can detect the fire. A large forest fire on the slope of a hill increases the area of the emitting surface by at least two orders of magnitude, back to within the range of human technology. We, therefore, can draw the conclusion that if the beetles were as sensitive to infrared radiation as the top-of-the-line infrared radiation detectors, a forest fire on a hillside at a 100.0 km distance would be detectable.

But human technology assumes a receiving surface of a square centimetre or so. The reason is that at those kinds of sensitivities, you encounter background fluctuations. The bigger the receiver area, the more the natural fluctuations average out. It is similar to the problem you run into with a cellphone far from the towers that relay the information; you often lose the connection. Bigger and better antennas help. According to Dr Evans, the beetle has numerous sensors, each the size of the radiation it is tuned to (about 3.0 μm), with spaces in between and a total sensing organ of a few tenths of a millimetre in diameter. It is the total active area of the organ that counts.

As mentioned before, Dr Evans measured the actual sensitivity of the insects. He gently mounted beetles at the exit of a prism monochromator and observed their reaction to the radiation coming from the instrument. Beetles twitch when they sense radiation on the organs on their sides. By varying the output wavelength and watching for the twitches, Dr Evans determined the wavelength range of sensitivity to be in the 3.0 μm range. He also measured the intensity of the radiation triggering the twitches. He found the threshold of reaction to the infrared radiation to be 6.0×10^{-5} W/cm^2 (Evans 1966), nothing like the 10^{-9} W/cm^2 our technology can provide.

Let's turn the earlier problem around. Based on the sensitivity Dr Evans measured, at what distance could our beetles sense the 5.0 m radius fire we assumed at the start?

At 1.0 km, we estimated an infrared intensity of 0.038 W/m^2 = 0.38×10^{-5} W/cm^2. That implies that the beetles, with a threshold sensitivity of 6.0×10^{-5} W/cm^2, could not even sense that fire at 1.0 km away. To sense the ball of fire, it would have to be at least $6.0 \times 10^{-5}/0.38 \times 10^{-5} = 16$ times more intense, a radius of $4.0 \times 5.0 = 20.0$ m, or else at 1/4 the distance (that is, 250.0 m).

There is another peculiar aspect to the infrared sensors. They are located on the sides of the beetle, not in the direction of flight. Why, then, should nature go through the evolutionary trouble to develop these sensors?

First, why should any beetle fly to a forest fire in the first place? On this point all entomologists agree. Cooked, fried or boiled tree remnants are more digestible by beetle larvae; hence, beetles have a preference for laying their eggs there.

If you were to lay your eggs in the warm ashes to get a head start on your competitors, you hopefully would avoid still-glowing embers that might fry your offspring (Evans 2010). What numbers can we generate with that in mind?

Problem 3

The infrared source is a glowing ember among the ashes, about 1 mm in radius. At what distance will a beetle, with a sensitivity of 6.0×10^{-5} W/cm^2, notice that source? As in Problem 1, use the temperature of 900 K and sensors that cover the range of 2.9–3.1 μm.

Answer

Calculations based on Planck's radiation law will give us a distance of 5.0 cm, which is reasonable for larval survival. Note also that the beetle has no need to have directional information as to the location of the embers. It just needs to avoid landing too near to any heat source.

Conclusion

It has been fun for me to apply my experimental background in near-infrared physics research to the biological phenomenon of beetles that seek out forest fires, as well as to follow in the footsteps of an entomologist friend. What I admire most about Dr Evans is not so much his skill in strictly biological matters but, rather, his willingness to dig into the physics rarely taught in biology. This showed me again the value of crossing scientific boundaries.

Can *Melanophila acuminata* sense forest fires from far away with its infrared sensors? The answer has to be no. The first reason is that the beetle has been tested in the laboratory for its sensitivity to the radiation in question, and it misses out by many orders of magnitude. Even if the creature had the sensitivity of the best man-made infrared detectors, the background radiation would swamp the radiation from the forest fires, in part because the organs that sense the radiation have poor directional discrimination. Any kind of eye (focusing) type structure would have helped, but that is not there.

However, the infrared sensors of the beetle come in handy once the fire has damped down. As we have seen, the sensors are more than adequate to find spots among the ashes where eggs can be safely laid and the larvae will have the desired food supply.

Appendix: Detailed Solutions

Problem 1

1a

The peak wavelength is given by Wien's displacement law: $\lambda T = 2.9 \times 10^{-3}$ mK. A temperature of approximately 600°C is approximately $600 + 273 = 900$ K. For $T = 900$ K, we get $\lambda = 2.9 \times 10^{-3}/900 = 3.2 \times 10^{-6}$ m $= 3.2\ \mu$m, close to the measured wavelength sensitivity of the beetle's sensors.

1b

A sphere of 10.0 m diameter, as seen from a distance of 1.0 km, can be considered a point source for the purposes of our calculation. Radiation is emitted according to the Boltzmann equation: $P = \varepsilon\sigma T^4 A$. A uniform hot sphere emits the radiation equally in all directions. For the ball of forest fire of height 10.0 m, the radius r will be 10.0/2 = 5.0 m. The total emitted radiation comes from the surface of a sphere of area $A = 4\pi r^2$. Substitute in the numbers: $P = \varepsilon\sigma T^4 A = (0.95)(5.7\ \Xi\ 10^{-8})(900)^4(4\pi)(5.0)^2$ in watts. That will be the radiative power leaving the assumed hot sphere. As you move away from the radiating sphere, the total power emitted stays the same, but it is spread over a larger area, $4\pi(1{,}000)^2$ m^2 at 1.0 km away. As a result, the intensity of the radiation from that source at that distance becomes $(0.95)(5.7\ \Xi\ 10^{-8})(900)^4(4\pi)(5.0)^2/4\pi(1{,}000)^2 = 0.89$ W/m^2 $= 8.9 \times 10^{-5}$ W/cm^2.

Keep that in context. The radiation incident on earth from the sun, the solar constant, is 1,353 W/m^2 = 0.1353 W/cm^2. Here are some more considerations. To keep the mathematics simple, we considered our source to be something like a single burning spherical tree. For the beetle at a distance of 1.0 km, a strip of such trees, 100.0 m wide or more, is a reasonable target in flat country. Should the fire be on the slope of a mountain, the hot source for the beetle's sensors can become thousands of square metres, each contributing almost equally at that distance.

1c

This is a nastier calculation because we have to use the wavelength dependence of Planck's radiation law. Here is the mathematical expression:

$$P(\lambda)\Delta\lambda = \frac{2\pi c^2 h}{\lambda^5}\frac{1}{e^{hc/\lambda kT}-1}\Delta\lambda$$

Where $P(\lambda)\Delta\lambda$ is the energy radiated per second per square metre of source over the wavelength range $\Delta\lambda$. We will evaluate $P(\lambda)\Delta\lambda$ at the middle and at the two extremes of the beetle's sensitivity (that is, at 3.0, 2.9 and 3.1 μm).

$$P(3.0\times10^{-6}) = \frac{2\pi c^2 h}{\lambda^5}\frac{1}{e^{hc/\lambda kT}-1} =$$

$$\frac{2\pi(3.0\times10^{8})^2(6.63\times10^{-34})}{(3.0\times10^{-6})^5}$$

$$\frac{1}{e^{(3.0\times10^{8})(6.63\times10^{-34})/(3.0\times10^{-6})(1.38\times10^{-23})900}-1}$$

Evaluating the expression, we get $P(3.0 \times 10^{-6}) = 7.45 \times 10^9$ W/m^2 over a (mathematical) one metre ωαϖελενγτη ιντερϖαλ. For $P(3.1 \times 10^6)$, we get $7.51\ \Xi\ 10^9$ W/μ^2 and for $P(2.9 \times 10^6)$, the expression works out to be $7.33\ \Xi\ 10^9$ W/μ^2, for an average of $7.43\ \Xi\ 10^9$ W/μ^2. Over a realistic wavelength ιντερϖαλ of 0.2 μm, from 2.9 to 3.1 μm instead of the mathematical one metre, we expect a radiation intensity of $(7.43\ \Xi\ 10^9)(0.2\ \Xi\ 10^{-6}) = 1.5\ \Xi\ 10^3$ W/μ^2 leaving the area of the forest fire (that is, the sphere of radius 5.0 m). At the supposed location of the beetle, 1.0 km from the fire, that same radiation will have spread over an area $4\pi(1{,}000)^2$ m^2. That area is $4\pi(1{,}000)^2/4\pi(5.0)^2 = 200^2 = 4 \times 10^4$ times greater than the radiation-emitting area, and therefore the beetle is exposed to radiation at an intensity of $1.5\ \Xi\ 10^3$ W/μ^2/$4 \times 10^4 = 0.038$ W/m^2 $= 3.8 \times 10^{-6}$ W/cm^2. That is quite a bit less than the total radiation calculated for the complete spectrum in 1a, as it should be. But it is also an order of magnitude less than the measured sensitivity of the beetle at 6.0×10^{-5} W/cm^2. Beetles should not be able to see the single-tree fire that far away.

Problem 2

2a

The total emitted radiation comes from the surface of a sphere of area $A = 4\pi r^2$. Substitute in the numbers: $P = \sigma T^4 A = (5.7\ \Xi\ 10^{-8})(5{,}762)^4(4\pi)(6.96 \times 10^8)^2$ in watts. That is the power of the radiation leaving the sun. As you move away from the sun, the total power emitted stays the same, but it is spread over a larger area, $4\pi(1.5 \times 10^{11})^2$ m^2 at 1.5×10^{11} km away. As a result, the intensity of the radiation from the sun at the surface of the earth becomes $(5.7\ \Xi\ 10^{-8})(5{,}762)^4(4\pi)(6.96 \times 10^8)^2/4\pi(1.5 \times 10^{11})^2 = 1{,}353$ W/m^2 = 0.1353 W/cm^2. This value of the radiation intensity is known as the solar constant.

2b

Start again with the wavelength dependence of Planck's radiation law. As in Problem 1,

$$P(\lambda)\Delta\lambda = \frac{2\pi c^2 h}{\lambda^5}\frac{1}{e^{hc/\lambda kT}-1}\Delta\lambda$$

where $P(\lambda)\Delta\lambda$ is the energy radiated per second per square metre of source over the wavelength range $\Delta\lambda$. We will again evaluate $P(\lambda)\Delta\lambda$ at the middle and at the two extremes of the required wavelength range (that is, at 3.0, 2.9 and 3.1 μm).

$$P(3.0\times10^{-6})=$$

$$\frac{2\pi c^2h}{\lambda^5}\frac{1}{e^{hc/\lambda kT}-1}=\frac{2\pi(3.0\times10^8)^2(6.63\times10^{-34})}{(3.0\times10^{-6})^5}$$

$$\frac{1}{e^{(3.0\times10^8)(6.63\times10^{-34})/(3.0\times10^{-6})(1.38\times10^{-23})5762}-1}$$

Evaluating the expression, we get $P(3.0 \times 10^{-6}) = 1.18 \times 10^{12}$ W/m^2 over a (mathematical) one metre ωαϖελενγτη ιντεϱϖαλ. For $P(3.1 \times 10^6)$ we get 1.05 Ξ 10^{12} W/μ^2, and for $P(2.9 \times 10^6)$ the expression works out to be 1.33 Ξ 10^{12} W/μ^2, for an average of 1.19 Ξ 10^{12} W/μ^2. Over the actual wavelength ιντεϱϖαλ of 0.2 μm, from 2.9 to 3.1 μm, we expect a radiation intensity of (1.19 Ξ 10^{12})(0.2 Ξ 10^{-6}) = 2.4 Ξ 10^{12} W/μ^2 leaving the sun's surface. At the surface of the earth, 1.5×10^{11} m from the sun, that same radiation will have spread over of an area $4\pi(1.5 \times 10^{11})^2$ m^2 resulting in an intensity of (2.4 Ξ 10^{12} W/μ^2)$(6.96 \times 10^8)^2/(1.5 \times 10^{11})^2 = 5.19$ W/m^2. If the surface of the countryside were a perfect reflector in the 3.0 μm range, it would be that bright in all directions.

Problem 3

We have to use Planck's radiation law in its wavelength dependence again:

$$P(\lambda)\Delta\lambda=\frac{2\pi c^2h}{\lambda^5}\frac{1}{e^{hc/\lambda kT}-1}\Delta\lambda$$

where $P(\lambda)\Delta\lambda$ is the energy radiated per second per square metre of source over the wavelength range $\Delta\lambda$. As was the case for Problem 1, we will evaluate $P(\lambda)\Delta\lambda$ at the middle and at the two extremes of the beetle's sensitivity (that is, at 3.0, 2.9 and 3.1 μm).

$$P(3.0\times10^{-6})=$$

$$\frac{2\pi c^2h}{\lambda^5}\frac{1}{e^{hc/\lambda kT}-1}=\frac{2\pi(3.0\times10^8)^2(6.63\times10^{-34})}{(3.0\times10^{-6})^5}$$

$$\frac{1}{e^{(3.0\times10^8)(6.63\times10^{-34})/(3.0\times10^{-6})(1.38\times10^{-23})900}-1}$$

Evaluating the expression, we get $P(3.0 \times 10^{-6}) = 7.45 \times 10^9$ W/m^2 over a (mathematical) one metre ωαϖελενγτη ιντεϱϖαλ. For $P(3.1 \times 10^6)$ we get 7.51 Ξ 10^9 W/μ^2, and for $P(2.9 \times 10^6)$ the expression works out to be 7.33 Ξ 10^9 W/μ^2, for an average of 7.43 Ξ 10^9 W/μ^2. Over a real wavelength range of only 0.2 μm, from 2.9 to 3.1 μm, we expect a radiation intensity of (7.43 Ξ 10^9)(0.2 Ξ 10^{-6}) = 1.5 Ξ 10^3 W/μ^2 = 0.15 W/cμ^2 leaving the area of the burning ember (that is, the sphere of radius 0.1 cm). At 1 cm from the ember, the intensity is down to 0.15 W/cμ^2/(10 mm/cm)^2 = 1.5 Ξ 10^{-3} W/cμ^2. At a distance d in centimetres, the intensity is 1.5 Ξ 10^{-3} W/cμ^2/d^2 = 6.0 Ξ 10^{-5} W/cμ^2 to get us to the maximum distance d the beetle can detect the burning ember. From the expressions, we get $d^2 = 25$, $d = 5.0$ cm. Reasonable for larval survival. Note also that the beetle has no need to have directional information as to the location of the embers. It just needs to avoid landing too near to any heat source.

Notes

1. See http://news.nationalgeographic.com/news/2003/03/0314_030314_secretweapons3.html (accessed June 4, 2013).

2. See, for example, Schmitz et al (2008).

References

Evans, W G. 1964. "Infra-Red Receptors in *Melanophila Acuminata* Degeer." *Nature* 202, no 4928 (April 11): 211.

———. 1966. "Perception of Infrared Radiation from Forest Fires by *Melanophila Acuminata* De Geer (Buprestidae, Coleoptera)." *Ecology* 47, no 6 (November): 1061–65.

———. 2010. "Reproductive Role of Infrared Radiation Sensors of *Melanophila acuminata* (Coleoptera: Buprestidae) at Forest Fires." *Annals of the Entomological Society of America* 103, no 6 (November): 823–26.

Evans, W G, and J E Kuster. 1980. "The Infrared Receptive Fields of *Melanophila acuminata* (Coleoptera: Buprestidae)." *The Canadian Entomologist* 112, no 2 (February): 211–16.

Schmitz, H, A Schmitz, E Kreiss, M Gebhardt and W Gronenberg. 2008. "Navigation to Forest Fires by Smoke and Infrared Reception: The Specialized Sensory Systems of 'Fire-Loving' Beetles." *Navigation* 55, no 2 (Summer): 137–45.

Strong, J. 1956. *Procedures in Experimental Physics.* New York: Prentice Hall.

Millsap and the Ring of Fire

Wytze Brouwer

Once in a while, during a busy year, a professor's thoughts turn to getting away from it all and relaxing for a few weeks. These feelings tend to arise in early February, in mid-April, at the end of June and early in October, not to forget the Christmas season.

Not that you can act on all these impulses—but you can dream of a warm place at the seaside or of sitting by a mountain stream with a fishing rod.

It was early February, and both Bert Millsap and I had the urge to go somewhere warm near the ocean. We talked to our wives and they agreed that a holiday was essential. But where should we go?

We all had our own ideas of where we would like to spend a couple weeks, but since Millsap had recently been spending his spare time studying the prevalence of earthquakes, he insisted that we go somewhere close to the Ring of Fire, that region on Earth where the major plates in the mantle are most likely to collide and cause major earthquakes.

Our wives came close to vetoing the idea, but I assured them that many places on the Ring of Fire are very safe and have experienced major earthquakes only once in several hundred years.

So we bought tickets to a resort in Guayabitos, Mexico. We reserved two rooms—in the deluxe area, of course, since Millsap likes his comforts. The only argument was about who would share a room with him. It might seem natural that Helen, his wife, would share his room. But over the years Helen has found that even she can only take her husband in small quantities. Even at home, they inhabit different suites in the same building, and thus remain quite happily married.

Since I reasoned persuasively that Bert could not share a room with my wife, and since I would sleep in the same room with him only over my dead body, Helen finally agreed to spend the two weeks in the fairly large suite with him.

While the rest of us unpacked, Bert went around the building to find out what to do in the case of *sismos*. Apparently, the procedure is very similar to what you should do in the case of *incendios*. Despite Millsap's elaborate plans, which he outlined for us, my own plans remained simple and unchanged: avoid elevators and head for the nearby hills.

After we finished unpacking, Millsap set up his simple portable seismology station, which seemed to be little more than a hanging paper cup, with a black marker coming out of a hole in the bottom and a drum-like device for rolling paper along the black marker.

We spent many relaxing days in the sunshine and even walked along the ocean, getting our bare feet wet up to the ankles. Several times we walked to a nearby town, La Penita, partly because we saw some alligators in a small creek on the way. The biggest surprise of the holiday was that Millsap had the energy to do that 45-minute walk. On occasion, while we walked back to Guayabitos along the beach, Millsap would take a taxi at the great cost of 30 pesos, which works out to approximately $2.50 in Canadian dollars.

One week went by, and to Millsap's dismay his portable seismology station had wasted a week's worth of recording paper and ink, with not even a tiny tremor showing. The rest of us were sure that Millsap's bedtime prayer each night was that we would be sent an earthquake measuring at least 6.0 on the Richter scale—but not all prayers are answered to Bert's satisfaction, anyway.

However, something about Bert's behaviour was beginning to puzzle me.

When the ladies or I wanted to buy something at the outdoor markets or in the little shops, it was my practice to haggle the price down a little, below what the shopkeeper quoted. For some reason, I felt that it was expected from us, and that the shopkeepers would be insulted if we didn't at least try. I was becoming reasonably successful at this, and was quite proud of myself. Not that I was saving that much money, because I usually tipped the shopkeeper most of the difference. As we left the shop, Bert would often lag behind us, and it would take him half a block to catch up again.

At some point I asked Helen what Bert could possibly be up to that kept him trailing behind us, after most of my successful purchases. Helen confessed that she was not sure but she thought that Bert was a bit embarrassed by my haggling. Here's this rich North American tourist haggling over the price of T-shirts and costume jewellery with a poor Mexican artisan, when I could well afford the price quoted.

"What I think Bert is doing is this," Helen said. "He slips the shop owner the difference between the price you paid and the price the shop owner originally quoted. He feels it will make the Mexicans more accepting of the tourists."

"Well, the soft-hearted sap!" was my response. "So he thinks I'm a typical hard-hearted tourist, eh? I'd better have a talk with him."

"Hey, Bert, you've been paying my international debts, have you? Didn't you notice that I usually tip the difference between the price I pay and the original asking price? And then you go up to the shopkeeper and pay that difference again? I wonder what these shopkeepers end up thinking about these crazy tourists, especially the short, fat one."

Bert just shrugged his shoulders. He didn't care. What's money after all? A few pesos here or there meant nothing to him, so don't get excited, Brouwer.

At least after this, Bert was not quite as embarrassed about my haggling and kept up with us a bit better.

Then came the fateful Wednesday night. We had just returned from a late dinner, and I was already in bed reading a mystery novel. My wife was in the bathroom, when someone pounded on the door.

"Earthquake, Brouwer! There's an earthquake! Come out and leave the building!"

Earthquake? I hadn't felt anything. I opened the door and an excited Millsap was hopping up and down, as pleased as punch.

"We had an earthquake, Brouwer! We have to evacuate the building!"

"First, show me your earthquake, Millsap. I'm not moving until I see some proof."

"Come to my room and see my seismograph record. It clearly shows that an earthquake occurred at 10:23, just four minutes ago."

I had a good look at the seismograph and, indeed, a small squiggle had occurred a few minutes before and lasted about 10 seconds.

"That's not much of an earthquake, Bert. I wouldn't get too excited about it yet."

"But it might be a precursor to a major quake. We have to get out of here and into the hills in case a tsunami happens!"

In situations like this, Millsap tends to go overboard, so I went down to the registration desk to see if they knew anything about an earthquake. They assured me that they were not aware of any *sismo* and that tiny earthquakes happened at least once a month and were nothing to worry about.

I came back up to our rooms and convinced our wives that we could safely stay in our beds for the night, but Millsap was not so easy to convince. He was already dressed to the hilt, equipped with water and food, and ready to camp out in the hills for the night. What was Helen to do? She had confidence in my judgment, but could she leave her husband to spend a lonely night up in the dark hills all by himself?

"Why don't you go with him, Brouwer? It would be much safer with the two of you."

"No, thanks, Helen. If Bert is determined to head out, let him go. He'll come back hungry (and maybe mosquito-bitten) for breakfast, and maybe he'll learn not to get overexcited about every little thing. Remember how he evacuated his house when he misread a radon monitor?" (See the archives for the sorry story.)

So the three of us stayed at the resort and had a good night's sleep. It's amazing how good a bed feels when you know someone is out in the woods trying to get comfortable on leaves and twigs.

The next morning, all refreshed, we were having a rather late breakfast when Millsap finally arrived, not looking quite as dishevelled and tired as we had expected. The reason became obvious when he explained to us that, after climbing about 50 yards into the hills, he came across a small Mexican house. With its lights on, it looked so inviting that he knocked on the door and invited himself in.

"I had several tequilas with the owner, and when it was bedtime they offered me a bed for 100 pesos, and I had a good night's sleep, and a wonderful breakfast with them. I wonder why we didn't have a major earthquake."

He almost looked sorry, but I suppose even Millsap was grateful that we had not perished in an earthquake or a tsunami. And we did some research later in the day and discovered that an earthquake measuring 5.8 on the Richter scale had indeed occurred at about the time Millsap figured—about 100 kilometres north of us, but well offshore.

So, another Millsap escapade ended quite happily, and we had a story to tell when we got back to the snowy north.

Millsap and the No-Zero Policy

Wytze Brouwer

"A shandy, please."

It was a Wednesday afternoon, and it was wet. An unusual all-day heavy rain had descended on the campus, and it had taken only a phone call or two to arrange a cozy after-class get-together at the Faculty Club.

The waiter brought my shandy and Bert Millsap's usual concoction. The nice thing about the Faculty Club is that you can order the strangest drinks and, after a few weeks, the waiters will automatically bring the right drink for the right person. Millsap's Rosemary Sunset was famous at the club because it combined more ingredients than any other member would even want to try.

"I hear this rain is going to change to snow overnight," ventured Brian Adams.

"What? Isn't this bad enough? It's the middle of May!"

Of course, some of the most devastating snowstorms on the prairies have occurred in late May, after the trees have budded, and branches bend or break under the heavy, wet snowfalls. So we weren't too surprised that the weather forecast had changed. *Dismayed* best described our attitude.

Millsap had been very quiet so far, but his face was an unusual purple colour. He looked a bit like a volcano, slowly building up steam before exploding. Of course, we suspected what was bringing Bert to the boil. The local and even national news had covered the story of a high school physics teacher's dismissal because he had continued to give his students grades of zero if their assignments were not completed in a reasonable time. Apparently, his school had adopted a no-zero policy for assessment, and the teacher had objected to the administration's interference in what he thought was his professional right as a teacher—to assess students in the way he felt best.

"Brouwer, are you aware of the fact that your profession is rife with idiots?"

Millsap almost whispered this accusation, as if he needed to control himself with an iron will.

"All professions have a good proportion of idiots, Millsap. In fact, from personal knowledge, your own field of psychology has probably managed to snag a greater proportion of idiots than physics."

"I'm not talking about physics, Brouwer. I seem to remember that you have a joint appointment in the Faculty of Education."

"So?"

"These so-called educational experts have decided on the basis of no evidence whatsoever that giving students who don't complete assignments a zero somehow warps their personalities and destroys their future hopes of successful careers."

"Just a minute, Millsap," Jenny Parsons interposed. "As usual you're exaggerating and generalizing all over the map. Who are you to say that these educators don't have good reasons for advising teachers not to assign zeros but, rather, to put the emphasis on finishing the assignments?"

"The only evidence ever cited is the case in which the researchers found that a small group of handicapped kids performed better if no zeros were awarded but students were encouraged to finish the assignments." Bert had indeed read some of the documents supposedly supporting the no-zero policy.

Brian jumped in. "But that's hardly evidence for the no-zero policy. Who in his right mind would even considering giving zeros to handicapped kids, when your only goal should be to encourage and help them?"

"But if not giving zeros to handicapped kids is more effective than punishing them with zeros, shouldn't this be true also for your general high school population?"

That was me, trying to keep the discussion on matters of principle, and away from personal attacks on my colleagues.

"Brouwer, if I were teaching one-on-one, I suppose I would consider never giving a zero, because I could devote my time to encouraging my student to finish every assignment, even if it took a bit more time. But in high school (or university), you've got at least 30 (or 300) students in most classes, and you don't have time for the paperwork, unless you insist that assignments be completed in a reasonable time. And if they aren't, a zero is appropriate."

Millsap was sitting back, satisfied that Adams was presenting his arguments more logically than he himself might have done.

"I suppose my own practice in biology," said Jenny, "is to use zeros as a matter of course. I've never thought about the philosophy of giving zeros. Students know the assignments have to be done by a certain date. I accept almost any excuse for a late paper, and I don't penalize students. But if the paper is not done by the time I hand the rest back, I give it a zero, without any qualms of conscience. By that time, it's the student's own choice. How about you, Brouwer?"

"My approach is very similar. I do threaten to take off a few marks if assignments are handed in late, but only 1 or 2 per cent, if necessary. But the ultimate deadline is a week later, when the assignments are returned. Then there's no point handing in late assignments, because students could just copy from the graded assignments of other students. I do usually give students a break by telling them I will count only their best five out of six assignments, so they are able to exercise some choice and don't need to worry if for some reason they weren't able to finish one of the assignments.

"But I have a different problem with the whole issue. I sometimes wonder if the proponents of the no-zero policy fundamentally misunderstand student assignments. It almost appears as if they feel that assignments are an imposition on students in order to make them earn a grade or something. I'm not particularly interested in the grades students get on assignments. In fact, the grades are almost a gift from me to them. But in the sciences, assignments are an essential part of the learning process. If certain skills are not mastered sequentially in math, physics or chemistry, students have little hope of mastering the next set of skills, which are based on the earlier ones. So, I choose my assignments very carefully to help students master the skills currently being taught so that they will have a chance for continued success. If I gave students the right to ignore an assignment, I would not be doing them a favour. Moreover, physics students are usually a dedicated group who understand how important assignments are."

That was the longest speech but one that I had ever given at the Faculty Club, and I was surprised that I hadn't been interrupted by what was traditionally a pretty impatient group—especially Millsap.

"So you would advise teachers to keep giving zeros in the public schools?" Jenny asked.

"No, I would advise teachers to try to get by without ever giving a zero. Encourage the kids to finish assignments because they have a positive effect on future learning. Give the students every break you can on late assignments, but remember that for some students, the external threat of a zero might motivate them to do the assignment.

"But if I were a classroom teacher in an elementary school, for example, I would never give a zero. My job as an elementary school teacher would be exclusively to encourage kids, to get them excited about learning. Elementary school is not the place to use threats or negative reinforcement. I would want to bring out the strength in every kid. But as kids grow up, in junior high school or later, they should slowly begin to take more responsibility for their learning. Certainly in high school, not completing assignments should be almost the sole responsibility of the students themselves, and I wouldn't hesitate to use a zero."

"So what happens in the meantime, Brouwer? Is the argument being resolved?"

"I think the argument will disappear within 20 years," postulated Millsap, who had been quiet for a long time. "I think with modern technology, learning will become much less teacher-centred and individualized. And with modern technology, learning will become more competency-based, so that students will have to show they have mastered certain skills before proceeding to the next one. There'll be no more ignoring assignments. You don't finish, you don't proceed to the next lesson."

Millsap may not have been far from the truth. Both sides of the current argument might be shown to fall short of the ideal. There will probably be no zeros in the education of the future. But there will be no place for unfinished assignments, either.

In the future, there might not even be grades but simply progress reports on how far students have progressed in their mastery of the skills they need. And they'll proceed at their own rate. Hopefully, that type of learning can lead to learning that is truly lifelong.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Specialist councils' role in promoting diversity, equity and human rights

Alberta's rapidly changing demographics are creating an exciting cultural diversity that is reflected in the province's urban and rural classrooms. The new landscape of the school provides an ideal context in which to teach students that strength lies in diversity. The challenge that teachers face is to capitalize on the energy of today's intercultural classroom mix to lay the groundwork for all students to succeed. To support teachers in their critical roles as leaders in inclusive education, in 2000 the Alberta Teachers' Association established the Diversity, Equity and Human Rights Committee (DEHRC).

DEHRC aims to assist educators in their legal, professional and ethical responsibilities to protect all students and to maintain safe, caring and inclusive learning environments. Topics of focus for DEHRC include intercultural education, inclusive learning communities, gender equity, UNESCO Associated Schools Project Network, sexual orientation and gender variance.

Here are some activities the DEHR committee undertakes:

- Studying, advising and making recommendations on policies that reflect respect for diversity, equity and human rights
- Offering annual Inclusive Learning Communities Grants (up to $2,000) to support activities that support inclusion
- Producing *Just in Time*, an electronic newsletter that can be found at www.teachers.ab.ca; Teaching in Alberta; Diversity, Equity and Human Rights.
- Providing and creating print and web-based teacher resources
- Creating a list of presenters on DEHR topics
- Supporting the Association instructor workshops on diversity

Specialist councils are uniquely situated to learn about diversity issues directly from teachers in the field who see how diversity issues play out in subject areas. Specialist council members are encouraged to share the challenges they may be facing in terms of diversity in their own classrooms and to incorporate these discussions into specialist council activities, publications and conferences.

Diversity, equity and human rights affect the work of all members. What are you doing to make a difference?

Further information about the work of the DEHR committee can be found on the Association's website at www.teachers.ab.ca under Teaching in Alberta, Diversity, Equity and Human Rights.

Alternatively, contact Andrea Berg, executive staff officer, Professional Development, at andrea.berg@ata.ab.ca for more information.

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