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Cultivating Constructivist Classrooms Through Evaluation of an Integrated Science Learning Environment

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The strategic incorporation of information technology (IT) into teacher education can foster constructivist teaching and learning practices in school classrooms. One design, the Integrated Science Learning Environment (ISLE) model, uses IT to holistically combine a variety of approaches to develop constructivist milieus. The goal of ISLE, common to other approaches as well, is to improve science education by bringing about conceptual change through authentic inquiry. According to Rosalind Driver and colleagues (1994, p. 7), "The challenge lies in helping learners to appropriate these models for themselves, to appreciate their domains of applicability and, within such domains, to be able to use them". Drawing on first-hand experience as a science teacher educator, this brief examination expands current themes described in the context of two different ISLE programs.

With the array of valid and reliable tools and efficient and simple techniques reviewed by Barry Fraser (2007), learning environments research adds an important perspective on documenting if and how programs are having an impact on school science. A common use of classroom environment assessments has been as dependent variables in evaluating educational innovations, as illustrated by Catherine Martin-Dunlop and Barry Fraser (2008). Integral to the ISLE model, innovative research methods used new forms of the Constructivist Learning Environment Survey (CLES) to quantify teacher and student perceptions of the emergent learning environments as dependent variables. Changing the teachers' learning environment was found to be associated with a similar change in their respective school learning environments, which can be linked to improved attitudes toward and achievement in science.

The purpose of this chapter is to encourage further innovations for improving practice and research in science education. After briefly describing the current context for reform, the following sections provide a closer look at technology-rich learning environments, the basic

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framework of the ISLE model, how the CLES enables multi-level evaluation of ISLE programs, and how some teachers are realising positive change in today's science classrooms.

RE-FORMING NEW LEARNING ENVIRONMENTS

Recent and rapid advances in science and technology have initiated a ripple that is reshaping the traditions of science education through distance education and teacher education. Regarding science teacher education, Robert Sherwood and Deborah Hanson (2008) reported that, despite limited NSF funding during 1996–2006, "several projects have been able to show results that have made their way into the peer reviewed literature" (p. 31). Increased interest in both teaching and learning combined with the political and social attention to education on a global scale has supported similarly rapid and significant advances in learning environments research (Fraser 2002). For example, Younghee Woo and Thomas Reeves (2007) elaborated how technology can enable more meaningful interaction – "an essential ingredient in any learning process" (p. 15) – in web-based learning. "Adopting new educational practices that promote the development of critical thinking, collaborative skills and creative ability constitutes a social demand of our time" (Pedagogical Institute 2002, p. 6).

Classroom teachers demonstrate wide individual differences in content knowledge and pedagogical skills that impact on the learning environment that they create for their students. On reviewing studies of curriculum integration for over a decade, John Wallace, Rachel Sheffield, Leonie Rennie and Grady Grenville (2007) noted that "the energy and goodwill of the participants in the reform process, and their capacity to translate reforms into positive classroom experiences, make the difference in changing classrooms" (p. 30). By placing science-related content into perspective and applying the principles of collaborative problem solving in a real-world setting, the ISLE model supports and encourages teachers in the implementation of new technologies and teaching strategies through activities that promote personal growth. With successful transfer, the same techniques used to deal with issues in the university are applied to integrating new understanding and expertise in schools.

In terms of evaluating ISLE programs, of primary theoretical importance, the scales of the CLES directly support the goals of educational reform. Table 1 matches the CLES scales to the standard stated as the primary goals for educational reform in the United States.

It is of primary methodological importance that numerous past studies available in the scholarly literature confirm the validity of the CLES in numerous countries and its usefulness in various research applications. Results reported in 15 studies since 1995 with direct relevance to ISLE evaluation validated the CLES with 11632 students ranging from kindergarten to adult. English, Korean, Mandarin and Spanish versions were administered in Australia, Korea, South Africa, Taiwan, and the United States (Florida, Iowa, Minnesota, Ohio and Texas). For example, Sharon Harwell and colleagues (2001) used the CLES in university-school collaborative action research while integrating technology into the curriculum. Although there were no significant changes in student perceptions of the classroom learning environment, results led teachers to construct a new set of questions and a new plan of action to bring their classroom learning environments into closer alignment with a constructivist perspective for teaching and learning. Significant cross-validations of translated versions of the CLES have been reported among Korean students by Heuin Baik Kim, Darrell Fisher and Barry Fraser (1999) and among Taiwanese students by Jill Aldridge, Barry Fraser, Peter Taylor and Chung-Chi Chen (2000).

Table 1 CLES scales matched to learning environment goals for educational reform in science

CLES Scale	Science Learning Environment Standard Statement
Personal Relevance	"Teachers help students learn about and internalize the values inherent in the practice of science by relying on those values to shape the ethos of the learning community."
Uncertainty of Science	"…they (the teachers) work diligently to establish a congenial and supportive learning environment where students feel safe to risk full participation, where unconventional theories are welcomed, and where students know that their conjectures and half-formed ideas will not be subject to ridicule."
Critical Voice	"…teachers recognize that the emotional response of some students to a lively, argumentative, inquiry-based classroom might never to venture an opinion or idea, thereby avoiding the risk of public failure."
Shared Control	"Accomplished science teachers deliberately foster settings in which students play active roles as science investigators in a mutually supportive learning community."
Student Negotiation	"They (the teachers) foster a sense of community by encouraging student interactions that show concern for others, by dealing constructively with socially inappropriate behaviour, and by appreciating and using humour."

(National Board for Professional Teaching Standards (2001, p. 25)

TECHNOLOGY-ENRICHED LEARNING ENVIRONMENTS

In the ISLE model, real-world applications of relevant tools and resources are covertly employed to join the university classroom and field experience seamlessly. The focus is intentionally shifted from the details of hardware and software to finding ways to improve teaching and enhance learning through the most appropriate method(s). The first ISLE evaluation of a teacher outreach program was conducted in 2000, before the university had a reliable online course management system and before the department had practical mobile technologies for teaching and learning science. Throughout this one-semester intensive course, a virtual field trip was used to improve teaching efficiency and effectiveness by providing a dynamic and accessible interface to specific information for review and reference. The teachers were active contributors from the start as assignments required them to conduct searches for appropriate web sites related to their personal and professional interests, access files and forms from the archives, and help to build and use the water chemistry database in real time. As a group, participants created a top-level concept map to represent the goal of their field studies that reflected the main topics: ecology, geology, information technology (implicit in the supporting materials), humankind and the environment. This provided a prescribed framework in which to collaborate, along with a purpose and direction for focusing their individual reports. During the 2004–2005 academic year, a second ISLE study involved evaluating a three-semester teacher quality program. Five topical units were linked through culminating 'teaching roadmap' presentations. Matched participants teamed to weave complementary experiences into multidisciplinary projects that defined the lesson context, pedagogical framework, logistical framework, classroom application details and cross-disciplinary connections. This helped to transform the facts gathered from an independent, subject-based division into an integrated, concept-based continuation. Teacher understanding developed as the focus flowed from general observations to specific details and back to the increasingly sharper 'big' picture.

Regardless of the context and content, implementation of IT strategically reinforces the conceptual design and therefore is evident in all stages of an ISLE program. During pre-trip segments, appropriate use of IT is demonstrated through: modeling, as teachers experience the integration of technology; observing, as teachers see technology applied for everyday operations; and researching, as teachers search the Internet for references and resources. In the field locale, appropriate use of IT is evident in: training, as teachers demonstrate the functionality of a range of tools; sampling, as teachers collect real-time data using various devices; and analysing and interpreting information, as teachers record and manipulate data with technology-enabled resources. During post-trip follow-up, appropriate use of IT is demonstrated through: facilitating, as instructors help teachers to support the presentation of content with applications of technology; organising, as teachers outline their reports and verify their content with electronic sources; and producing, as teachers use software tools to create their contributions to the final product.

Bringing teachers, technology, students and learning together requires a new model of education that is practical for today's teachers and suitable for tomorrow's students. According to Clayton Christensen and colleagues (2008, p. 91) this notion is supported by the fact that "public education enrollments in online classes… are exhibiting the classic signs of disruption as they have skyrocketed from 45,000 in 2000 to roughly 1 million today". Simply 'cramming' technology into traditional instructional practices does not automatically increase student-centred learning and project-based teaching. Demonstrating what is possible, Ann Novak and Joseph Krajcik (2006) detailed ways that learning technologies have been embedded into practice to support children in acquiring deep and integrated understandings. Fortunately, the same technologies that have enabled 'anywhere-anytime', science in the real-world have equipped more people to learn 'everywhere-all-the-time', thus creating new realms for leveraging learning environments research. However, for now, challenged by stretched budgets (time and money), most science education and teacher education still occur within established classroom limits.

THE INTEGRATED SCIENCE LEARNING ENVIRONMENT (ISLE)

"In an era of dramatic new technology resources and new standards in science education in which learning by inquiry has been given renewed central status" Avi Hofstein and Vincent Lunetta (2004, p. 28) updated their 1982 review of research on the school science laboratory. Among other things, they added two studies in which student perceptions of science laboratory learning environments suggested open-endedness (the extent to which the activity emphasises an open-ended approach to investigation) and integration (the extent to which the laboratory activities are integrated with non-laboratory activities in the classroom) were important outcomes. Many other successful studies have aimed to integrate certain technologies or assessments or disciplines or activities. For example, Carol Stuessy and Jane Metty (2007) documented the impact of a science teacher's participation in the Learning Research Cycle, a model designed to bridge research and practice in both university and public school contexts. To emphasise connections between the eight stages, a web-based "community portal was used to connect teachers, graduate-student mentors, instructors, and scientists in and across small mentoring groups and summer classes" (p. 729).

Three key aspects distinguish the ISLE model from other teacher development programs:

1. ISLE models the integration of IT into the university classroom and curriculum, as they might be implemented in the school classroom. By actually experiencing the appropriate and effective use of IT in educational practice, teachers can appreciate the value of new tools and resources.
2. ISLE encompasses the field trip, as well as the university and school classroom milieus. By focusing on the common element, the individual, experience can be internalised and thereby naturally transferred among the physical settings.
3. ISLE seamlessly presents IT as a means to an end, not the end itself. By selecting and applying appropriate tools and resources, the benefits (rather than the challenges) can be maximised.

Figure 1 shows how a divergent affective approach can be shifted to realise a single effective plane defined by each unique learner. The instructor strategically teaches along distinct axes while students independently adjust their positions along each until the conceptual frameworks merge for meaningful learning that naturally transfers into other settings. This realisation occurs throughout a program due to variations in prior knowledge and learning preferences.

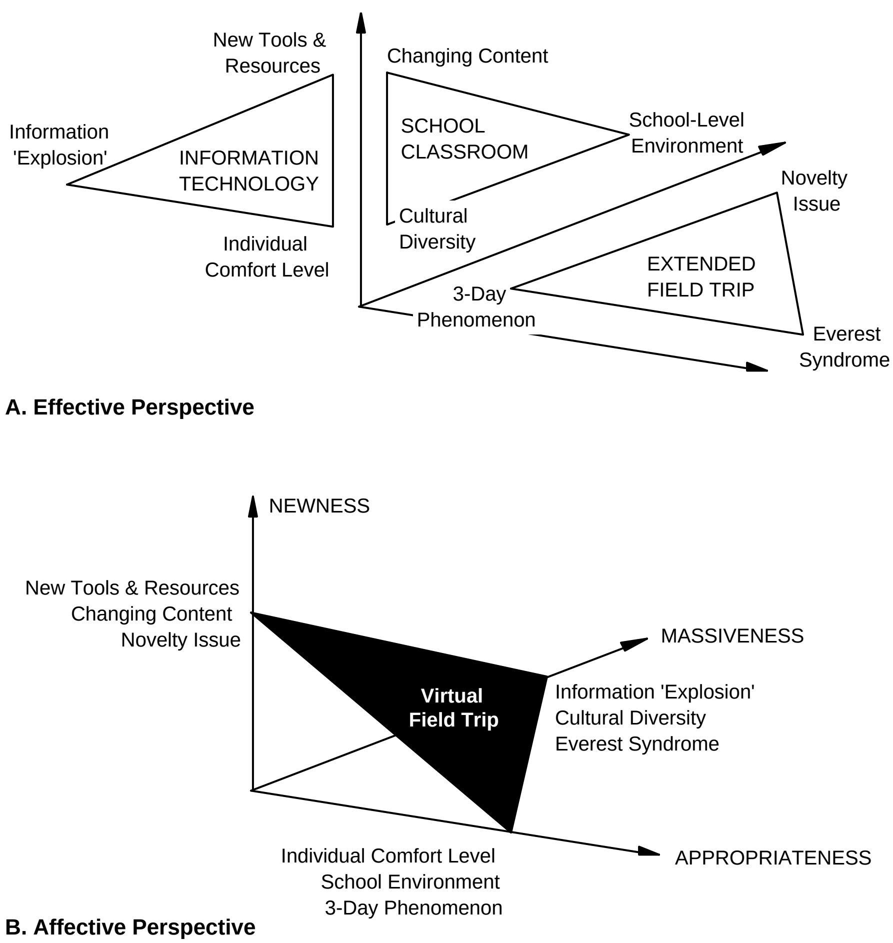

Figure 1 Merging of perspectives through the ISLE model

A novel sequence of experience, reflection, generalisation and application centred on a single CLES scale provides the scaffolding for each class, as well as for each lesson within the class. The cyclical repetition illuminates the commonalities and interdependencies of each concept. Participants are exposed to activities and instruction in a repeated hierarchical fashion. Movement along any one of the three major axes can catalyse change along each of the two other axes in the ISLE model. Regardless of the form, the key to attaining true integration is to create a comfortable framework to guide exploration and enable discovery that incorporates an interactive sequence of experience and reflection for teachers and their students. Innovative models for science education are being designed with the intention of, as explained by James Zull (2002), "creating conditions that lead to change in a learner's brain. We can't get inside and rewire a brain, but we can arrange things so that it gets rewired. If we are skilled, we can set up conditions that favor this rewiring, and we can create an environment that nurtures it" (p. 5).

CONSTRUCTIVIST LEARNING ENVIRONMENT SURVEY (CLES)

In the Project 2061 *Blueprints for Reform* (AAAS 1998), one suggested approach for improving science teacher education is that "students should be allowed to become active learners, have first-hand experience with making connections between their own ideas and the knowledge they develop in courses, and participate in classes where faculty model a teaching style that is conducive to active learning" (Teacher Education, ¶ 11). The generally-accepted principles of constructivist teaching guide the design of ISLE-based programs, providing a common thread throughout the coursework and the formative and summative evaluation of the program. In response to the need to assess innovative classroom environments, like ISLE, the CLES was developed by Peter Taylor, Barry Fraser and Darrell Fisher (1997) with a psychological view of learning that focused on students as co-constructors of their own knowledge. A unique aspect of the CLES is that items from the same scale are grouped together. The original 30-item version contains six items with a five-point frequency response scale (5=Almost Always, 4=Often, 3=Sometimes, 2=Seldom, and 1=Almost Never) in five scales:

1. Personal Relevance (relevance of learning to students' lives)
2. Uncertainty of Science (provisional status of scientific knowledge)
3. Critical Voice (legitimacy of expressing a critical opinion)
4. Shared Control (participation in planning, conducting and assessing of learning)
5. Student Negotiation (involvement with other students in assessing viability of new ideas).

The impact of the ISLE program on teachers and their students was investigated through multiple administrations of the CLES, including two modified versions described by Rebekah Nix, Barry Fraser and Cynthia Ledbetter (2005). Figure 2 shows how different participants are able to evaluate two different learning environments using three versions of a single instrument. At the end of formal instruction, the adult form is used to assess teacher perceptions of the university teaching. Several months later, the comparative teacher form allows the same teachers to assess the degree of constructivist practice in the learning environments that they create as teachers in their school settings. This evaluation is supported by their respective students' assessment of the degree of constructivist practice in the same school classroom on the comparative student form. With two separate response blocks for each item presented in side-by-side columns (THIS and OTHER), the CLES-CS asks students to compare the degree to which they felt that the principles of constructivism have been implemented in the class taught by their ISLE teacher (THIS) relative to classes taught by other teachers in their school (OTHER).

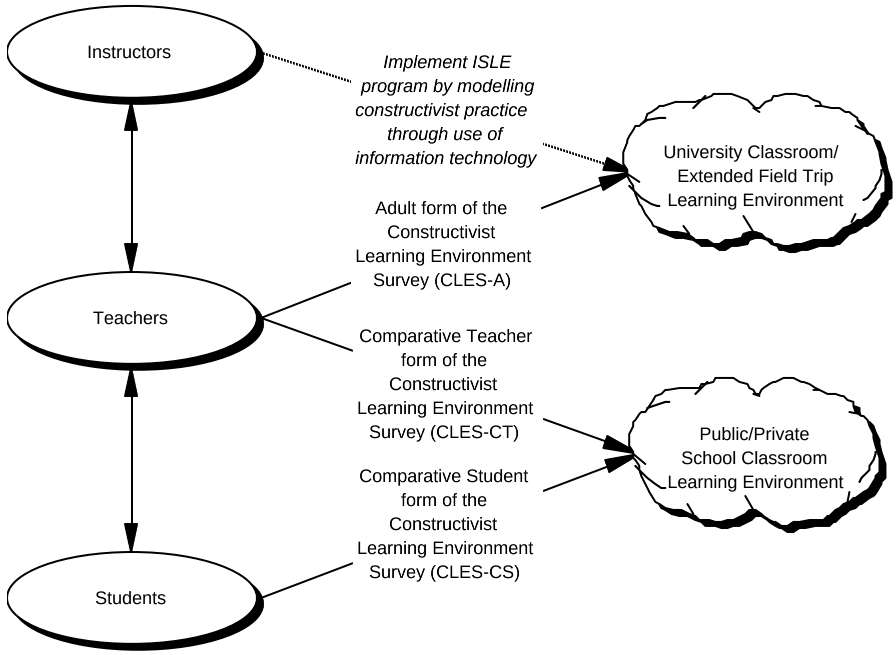

Figure 2 Multilevel assessment of ISLE model enabled by three versions of the CLES

Using data collected from 1079 students in 59 classes in north Texas, principal components factor analysis with varimax rotation and Kaiser normalization confirmed the *a priori* structure of the 30-item CLES-CS. The factor structure, internal consistency reliability, discriminant validity and the ability to distinguish between different classes and groups were supported for the comparative cases of the CLES-CS (Nix et al. 2005). Concurrent with the first ISLE study (Nix 2002), Bruce Johnson and Robert McClure (2004) developed a shorter and modified CLES and, for a different sample of teachers and students, reported that the new version exhibited strong internal consistency reliability. Consequently, it was used for the second ISLE evaluation. The uncertainty scale was omitted (because of its limited direct relevance to the overall study) to form a 16-item four-scale version (CLES2). For the responses from a second ISLE sample of 845 school students, principal axis factoring with oblique rotation and Kaiser normalization was conducted separately for the 16 items of the CLES2-CS for THIS and OTHER cases. The *a priori* four-factor structure was replicated perfectly and every item was retained (as its factor loading was greater than 0.40 on its own scale and less than 0.40 on the other three scales). The proportion of variance accounted for by different scales ranged from 6.77% to 16.19% (with a total of 44.17%) for THIS class and from 6.44% to 15.15% (with a total of 42.27%) for OTHER classes. Overall, results support the factorial validity of the 16-item CLES2. The alpha coefficients of different scales ranged from 0.60 to 0.97 for THIS and from 0.62 to 0.77 for OTHER, representing satisfactory reliability for these shorter scales.

CHANGING SCIENCE CLASSROOM LEARNING ENVIRONMENTS

Learning environments research has a broad range of applicability for today's diverse educational issues. These ISLE studies provide another example of the use of learning environment variables in educational program evaluation. A combination of qualitative methods and quantitative measures (Tobin and Fraser 1998) provided insight into the near- and far-term effects of the ISLE programs to answer the general question of whether changing teachers' learning environments might affect a change in their respective students' learning environments. Modified and shortened versions of the CLES were found to be valid, economical and useful for program evaluation. Limited to the north Texas area, quantitative data suggest that, in terms of the scales of the CLES, instructors were successful in fostering a constructivist learning environment in the university classroom as perceived by the teachers, and participating teachers were successful in fostering more constructivist learning environments compared to other classrooms at their same school as perceived by their school students.

By creating a virtual field trip product in the first ISLE implementation, both science and non-science teachers interconnected the ISLE experiences to support their specific teaching areas. Using the individual student as the unit of analysis, differences between the classroom environments of the ISLE science teachers and of other teachers in the same school were statistically significant ($p<0.01$) for Personal Relevance and Uncertainty of Science. Also, for Personal Relevance and Uncertainty of Science, differences between the science classroom learning environments of ISLE teachers and of teachers who attended alternative field trip programs not based on the ISLE model were statistically significant ($p<0.01$). In light of qualitative evidence, effect sizes suggested that the ISLE program could be educationally important for improving the learning environment indicators over which the teachers' evidently feel that they have some control. Although the first evaluation of the ISLE model within a summer short course attested to the model's success, it is noteworthy that the effect sizes were considerably larger in the second evaluation of the model over a three-semester time period. Using the CLES2-CS, the effectiveness of the second and longer ISLE program was evaluated partially in terms of the degree to which teachers implemented constructivist pedagogy in their secondary school classrooms, as perceived by the 845 students of the science teachers who had experienced ISLE. Differences between the classroom environments of the classroom environments of the ISLE science teachers and of other teachers in the same school were statistically significant for all four CLES scales (Personal Relevance, Shared Control, Critical Voice, and Student Negotiation), indicating that students perceived the participant teachers' classrooms as more constructivist than other teachers' classrooms in the same school. As suggested, the smaller effect sizes (around one-tenth of a standard deviation for Student Negotiation) could suggest areas over which the school administration appears to have strict control. By the same token, the larger effect sizes (nearly one standard deviation for Personal Relevance) suggests that the program could have had an educationally-important effect in improving the indicators over which teachers evidently feel they have some control. Overall, the data suggest that the emergent programs were effective in terms of the degree of implementation of constructivist teaching approaches in the ISLE teachers' school classrooms, as perceived by their students.

Consistent with previous studies, the ISLE model offers a broad context for enculturation of the constructivist paradigm. Because of the influence of numerous school-level factors, this sort of pedagogical change is difficult to realise in individual classrooms according to Catherine Milne and Peter Taylor (2000). In the second ISLE study, qualitative data led to four main assertions with respect to the implementation of constructivist teaching-learning practices:

- An interdisciplinary team approach to program design and delivery provides a critical perspective.
- Teacher efficacy must be founded on a solid base of content knowledge.
- A teacher's intimate and practical understanding of a subject is prerequisite for successful incorporation of new pedagogical skills.
- A working knowledge of and the availability of new tools and current resources, along with an active peer network, ultimately determine a teacher's facility to enhance his/her students' learning environment.

In terms of the implications of the potential for technology-rich science learning environments, the scales of the CLES can also be linked to pedagogical practices. Table 2 matches the CLES scales to excerpts from a proposed framework developed from a focused review of information and communication technology (ICT) use in science education (Webb 2005).

Table 2. Constructivist Learning Environment Survey scales matched to pedagogical aspects of information and communication technology use in science education

CLES Scale	Implications of ICT Affordances for Teachers and Students in an Integrated Pedagogy
Personal Relevance	"Teachers need to know about these affordances and… then need to use this knowledge of affordances together with a wide range of other types of knowledge… to plan activities that will lead to learning and will motivate their students."
Uncertainty of Science	"Computer simulations, Internet-supported student research projects and computer-based modelling provide new affordances that enable students to gain a wider range of experience relating to science in the real world."
Critical Voice	"The affordances provided by ICT-rich environments to support students' self-management free teachers to focus on questioning and negotiation of meaning."
Shared Control	"… the development of formative assessment pedagogy has enabled students themselves to identify their needs, and hence play a larger role in planning for their learning."
Student Negotiation	"Increasing discussion between teachers and students about learning processes and opportunities for learning will enable students to negotiate the planning of their own learning."

(Webb 2005, pp. 728-729)

A growing body of literature indicates that the ability to investigate learning environments in longitudinal, cross-cultural and multidimensional studies conducted across grade levels, content areas and contexts enables versatile designs that can illuminate critical associations of theory and practice that can be overlooked or underestimated in one-time, localised or field-delimited research. By jointly considering the physical and psychosocial learning environments in a single study of Canadian and Australian students' satisfaction, David Zandvliet and Barry Fraser (2005) identified important factors for a new model of educational productivity in computer networked classrooms. Similarly, learning environments research offers great potential for improving science teaching and learning as collaborators seek to bridge the gaps between traditionally-separated fields. For instance, despite scientific and pragmatic challenges for bridging education and neuroscience (Varma et al. 2008), one evaluation significantly established a causal relationship between the improvement of Grade 9 earth science students' learning and the utilisation of Visual Thinking Networks (Longo et al. 2002). Already underway, preliminary results from testing for the third implementation of the ISLE model indicate that the same metacognitive learning strategy improved abstract reasoning abilities in adult learners enrolled in an integrated distance education course for science teachers (Nix and Longo 2008). Designed to exploit multiple technologies and alternative assessments, the modular content is one more step toward a truly student-centric model for science teacher education. Supported by the American Educational Research Association's release of *Estimating Causal Effects Using Experimental and Observational Design* (Schneider et al. 2007), the next step is to explore ways to connect learning environment correlations to neurocognitive causes to inform future action research that science teachers can conduct within their ever-changing classrooms. As suggested by John Cannon (1997), "the CLES could be used as a means for the teachers [of college courses] to measure the efficacy of their efforts to move to more constructivist-oriented teaching and learning environments" (p. 70).

Barry Fraser and Jane Kahle's (2007) secondary analysis of 1995–1997 data from Statewide Systemic Initiatives found that "the classroom environment (defined as the use of standards-based teaching practices) accounted for variance in both achievement and attitudes scores over and above that attributable to either the home or peer environment" (p. 1905). The traditions of learning environments research provide a common language and promising methods to meet the new challenges facing educators and researchers in science and education in a technology-rich world. The literature resoundingly states that the crucial component of teaching and learning is the teacher and his/her pedagogical approaches. Fortunately, these ISLE studies and other similar investigations indicate that today's university and school teachers are making a positive difference in science education.

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