LEARNING SCIENCE THROUGH ENGAGING WITH ITS EPISTEMIC REPRESENTATIONAL PRACTICES

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Abstract: This group of papers explores the development of student understanding and application of the discursive tools of science to reason in this subject, as the basis for classroom practices that parallel scientists’ knowledge production practices. We explore how this account of the disciplinary literacies of science can be enabled through effective pedagogies. The papers draw on research from Australia and Sweden that have overlapping agendas and theoretical perspectives including pragmatism (Peirce 1931-58; Dewey 1938/1997), social semiotics (Kress et al. 2001) and socio-cultural perspectives on language and learning (Lemke, 2004). The papers examine the role of language/multimodal representations in generating knowledge claims in science classrooms, the classroom epistemologies that support learning, and assessment practices from this perspective. A large body of conceptual change research has identified trenchant problems in conceptual learning in science, spawning long-standing and ongoing programs to address this. By redefining the problem in terms of language and representation, we aim to offer a way forward to support student engagement and learning in science.

Keywords: Student learning in science, representation, pragmatism, socio-cultural perspectives, epistemic

BACKGROUND, FRAMEWORK AND PURPOSE

Much conceptual change research has identified trenchant problems in conceptual learning in science, spawning various long-standing programs to address this (Treagust & Duit, 2008). However, conceptual change perspectives are also changing to accommodate complexities uncovered by recent research and new theoretical perspectives (Vosniadou, 2008). Recent work in cognitive science (Klein, 2006; Tytler & Prain, 2010) emphasizes knowledge and learning as fundamentally situated, strongly dependent on perceptions and perceptual processing (Barsalou, 2003) and on informal reasoning, including pattern completion, association, and model based reasoning (Lehrer & Schauble, 2006a). Part of this work recognizes the fundamental role of language and representation as constituting thought rather than being a by-product of internal, stable mental constructs. There is increasing interest in socio-cultural theories that frame learning in terms of induction into the discursive practices through which the science community generates and validates ideas about the world (Lemke,
2004). From this perspective, learning and knowing is not primarily thought of as the inculcation, through formal logics, of uniquely and verbally defined conceptual entities, but rather as a process of increasing mastery of the multi-modal discursive tools and practices used by the scientific community.

Researchers have focused extensively on learning through inquiry, in representing investigative processes of science in the classroom to capture student engagement through exploration of ideas. This symposium explores a pragmatist, semiotic perspective on teaching and learning that brings notions of product and process together. From this pragmatist perspective (Peirce 1931-58; Dewey 1938/1997), knowledge and learning derive their meaning from their use, and conceptual entities are profoundly contextual in nature. These ideas are captured in recent work on the nature of science in which the existence of an irreducible ‘scientific method’ has been questioned and science is seen as a human practice, responsive to the contextual communicative needs of research laboratories and wider communities of practice (Duschl & Grandy, 2008).

The three papers in this symposium are grounded in larger Australian and Swedish research programs exploring with teachers the implications of these theoretical ideas for teaching, learning and assessment in science. The projects are strongly grounded in pragmatist perspectives, drawing on Peirce (1931-58), and Dewey (1938/1997), and on socio-cultural perspectives that view learning as induction into the epistemic practices of science through its multi-modal discursive tools (Lehrer & Schauble, 2006b; Lemke, 2004). The programs are aligned broadly with social semiotic perspectives (Kress et al., 2001), but the Australian project in particular focuses on student generation and negotiation of representations as a basis for quality reasoning and learning (Ford & Forman, 2006; Greeno & Hall, 1997). In this way, student engagement with the epistemic practices of science is seen as a fundamental condition for quality learning. Thus, the symposium explores linking the epistemic practices of science, the nature of conceptual learning, and classroom epistemological processes, to enable quality learning.

METHODS

In each paper we report on empirical classroom results based on video capture of student and teacher interactions, and use discourse analysis to understand the nature of the interactions between teachers, student, and artefacts that lead to quality learning. In the Australian cases the data also included interviews with students and teachers, pre and post tests, and student-produced artefacts. The analyses will explore:

1. The key features of a pedagogy based on student generation and negotiation of representations, and how such a pedagogy works to support quality learning;
2. The possibility of using semiotic resources to establish continuity between proximate and ultimate scientific learning purposes; and
3. The implications of a representational perspective for assessment in science.

STUDY 1: LEARNING SCIENCE THROUGH REPRESENTATIONAL CONSTRUCTION

Background, Framework and Purposes

Learning science in school is now broadly understood as learning the literacies of a specific discourse community, using a range of subject-specific and general representational tools to construct and justify evidence-based claims about the natural world (Kress et al. 2001;
Researchers in classroom studies where students were guided to construct their own representations of scientific ideas (Carolan, Prain & Waldrip, 2008; Ford & Forman, 2006; Greeno & Hall, 1997) have noted the importance of teacher and student negotiation of representational meaning and of students having opportunities to explore, elaborate, re-represent and coordinate representations to interpret science phenomena. There is growing evidence (Hubber, 2010; Hubber, Tytler & Haslam, 2010;) of increased student engagement and improved learning outcomes from these processes. This paper reports on aspects of an Australian project where the researchers worked with teachers to develop and validate a pedagogy based on student generation and negotiation of representations. Research questions include: 1) What are the key features of a pedagogy based on student generation of multi-modal science representations? 2) How does this pedagogy support student reasoning in science, and 3) What evidence is there that this approach improves students’ conceptual learning?

Methods
The research team worked with four experienced primary and secondary teachers to develop a series of teaching sequences on science topics that the conceptual change literature has shown to present learning difficulties. The sequences focused explicitly on student generation and negotiation of representations related to key concepts. In working with the teachers over two years, we developed a set of pedagogical principles based on our experience and on the theoretical ideas described above. The teachers’ practices, student-teacher interactions, and student activity and discussion were monitored using classroom video capture. Key lessons were coded using an emergent scheme generated using Studiocode software, to make apparent the patterns of pedagogical moves and to explore the key features that could be considered fundamental to a representation-intensive pedagogy.

Teaching and learning sequences were selectively transcribed and subjected to ethnographic analysis to identify the extent to which, and in what ways, the pedagogical principles were exemplified, and for evidence of ways in which the focus on representational clarification supported reasoning and learning about key science ideas. Students were interviewed about their learning, and teachers about their perceptions of the effectiveness of aspects of the sequence. Student workbooks were collected to provide a continuous record of representational work. Pre- and post- test data were analyzed for evidence of improved understanding, flexibility representation generation, and capacity to transfer ideas to other relevant phenomena.

Results
The pedagogy has the following key principles:

1. The sequencing of representational challenges involving students generating representations to actively explore and make claims about phenomena, involving a) identifying appropriate representations underpinning key concepts; b) establishing a representational need, and c) working towards alignment of student generated and canonical representations.

2. Explicit discussion of representations, including a) their selective purpose, b) group agreement on generative representations, c) form and function, and d) the adequacy of representations.

3. Meaningful learning through representational/perceptual mapping between objects/events and representations.

4. Ongoing and summative assessment focusing on the adequacy and coordination of representations.
Moreover, analysis of the patterns of conceptual clarification and orientation, representational challenges, clarification and negotiation of representations, and explanation/resolution showed similar pathways for lessons but differences depending on year level, place of the lesson in the sequence, and topic.

Analysis of teacher/student exchanges and student artifacts demonstrated a strong alignment of the pedagogy with inquiry principles, but with strong framing of representational exploration leading to appreciation of canonical forms.

We argue that this constraint on inquiry offers a productive way forward for classroom practice that relates the exploratory, epistemic practices of science, needing to represent the canonical knowledge forms as a key target for science curricula. Lesson transcripts, interviews, and post-test results are used to show evidence of significant reasoning and learning. The analysis of reasoning is linked to the use of representations as epistemic tools in science knowledge-building, and draws on Peirce’s (1931-58) triadic model of meaning making, and notions of affordances to identify the way representations selectively focus and constrain attention on aspects of the problem space. Teacher framing of the use of multiple, selective representations and student understanding of the partial and selective nature of representations will be illustrated.

**Conclusions and implications**

There is increasing agreement that learning involves a process of induction into specific discipline-based discursive practices, and is mediated by representations as the epistemic tools of science. This research represents a serious attempt to translate these theoretical insights into a practical classroom pedagogy that can effectively frame learning in science. This program has both practical significance for teacher practice and teacher education, and theoretical significance in bringing science classrooms and science practice into closer alignment. A re-interpretation of conceptual problems in learning science in terms of representational issues, and a program to translate this into a pedagogy, shows promise of addressing problems in learning science that are well established in the conceptual change literature.

**STUDY 2: USING ORGANISING PURPOSES TO SUPPORT SEMIOTIC RESOURCE USE IN SCHOOL SCIENCE**

**Background and Aims**

In this study we discuss how educational research in semiotics and on representation use in science classrooms can be supported by a pragmatically-oriented approach to science education research. The aim is to demonstrate a heuristic that can be used to support teachers in scaffolding students’ conceptual learning and agency in science subjects. The unit of analysis is action and activities (including talk and the use of other semiotic resources), rather than mental entities, and hence important aspects of learning are studied as visible processes in communication and interaction as mediated by different semiotic resources and artefacts (Kress et al 2001; Säljö & Bergqvist 1997).

In this study we supplement earlier research within this field with the pragmatist notion about how the progression of learning can be understood as oriented by **proximate purposes**, which the teacher needs to make continuous with the **ultimate purposes** of an educational sequence jointly with the students (Johansson & Wickman, 2011; Wickman & Ligozat, 2011). These two kinds of purposes make up the **organising purposes** of a teaching sequence. The ultimate purposes or aims belong to the new kinds of scientific practices with concepts that are not yet familiar to the students (here we illustrate the concepts of friction, motion and
force as such ultimate purposes of a lesson). The proximate purposes belong to activities where students are given more familiar topics to study and discuss. A proximate activity of relevance for the ultimate aim of learning about friction and motion is for instance why we have tyres on our cars. Dewey, (1938/1997) called such proximate purposes that make sense and give agency to the student ends-in-view. A key task for the teacher is to find proximate purposes that work as ends-in-view to the students and that the teacher also can make continuous with the ultimate purposes of the lesson. The ultimate purposes make sense to the teacher, but the teacher has to translate them and make the students understand how the activity with ends-in-view also deals with the ultimate purposes. The praxis of using ends-in-view is commonplace in teaching, although their continuity with more ultimate goals of science teaching is rarely examined by educational researchers. The concept of ends-in-view originates from Dewey’s (1938/1997) thinking about progression (“growth” in Dewey’s terminology) as creating continuity between the prior experiences of students (including their use of semiotic resources), the current situation, and the new kinds of practices, concept uses and semiotic resources that students are introduced to. Our research questions in this study are: (1) How are the students’ and teachers’ language use, semiotic resource use and experiences made continuous in two different classrooms? (2) How may a teacher use the organising purposes to support this continuity for learning in science?

Methodology
In this paper we analyze two teaching sequences. The first is from a Swedish Year 5 school class studying science (Johansson & Wickman, 2011), which give a full analysis of the conversations in the class. The ultimate learning purpose for the lessons is about how friction facilitates or impedes motion. The teacher introduces this through more proximate purposes. We have studied two such proximate purposes used by the teacher: 1) why cars have tyres, and 2) that a vehicle can continue to travel indefinitely if there is no resistance at all. Events in the classroom were filmed and transcribed. The second analysed teaching sequence is from an Australian study using representations as semiotic resources to introduce the concept of force in Year 7 (Hubber, Tytler & Haslam, 2010; Hubber, 2010). We coded situations in the classrooms as dealing with either proximate or ultimate purposes and the associated semiotic resources as colloquial language, inter-language, and science language. The idea of continuity between the every-day and scientific uses of language has been developed by Wallace (2004) and Olander (2010). As the method for analysing the continuity regarding the organising purposes effected by the semiotic resources and experiences related to in the classroom we used Practical Epistemology Analysis (PEA), which is based on Dewey’s (1938/97) ideas, and broader investigations into language and action (Wickman & Östman, 2002).

Findings
The Swedish classroom study demonstrates how the teacher first creates a situation where the proximate purpose of why we have tyres on our cars functions as an end-in-view to the students and helps them to take part in the conversation. The predominance of student experiences and student language in the conversation helps make it possible for students to understand why we have tyres on our cars. A short excerpt from the conversation illustrates this:

Teacher: But what did you have to say about this, why do you think that we have tyres on our cars then? That’s interesting, is it not, especially now that different ideas are floating around? Yes!

Erik: Because otherwise we won’t get anywhere, I mean then we get a grip, because without, if you didn’t have that rubber on the tyres, then you’d just move around, you wouldn’t get any, anywhere.
However, during the rest of the conversation about why we have tyres on our cars the teacher does not relate the proximate purpose to the ultimate purpose, so the students are not offered the possibility of seeing how only certain aspects of what is treated from the proximate purpose are relevant to the ultimate one about friction. In the conversation the two organising purposes are not made continuous in the sense that the concepts of friction and motion are related to the student experiences and word usage (e.g. grip, move around) regarding why we have tyres on our cars.

Neither in the second situation, about how a vehicle can continue to travel indefinitely if there were no friction, are the proximate and ultimate purposes clearly related to each other in the conversations between the teacher and the students. This conversation starts like this:

Teacher: So friction makes it, it stop, this resistance, so that it doesn’t continue for ever. If there wasn’t any resistance anywhere, air resistance like you have felt with the car and no resistance on the road or in any of these parts, then these vehicles when they are given a push, they would continue for ever.

Erik: Would they do that then?!
Teacher: Yes! If there wasn’t any resistance anywhere. Then this force that the vehicle has received would continue for ever.
Erik: What if there is an uphill slope?
Teacher: Yes then there’d be resistance immediately, right.
Erik: Yes, exactly!

The students do not construe relationships jointly with the teacher about how the experiences and words used by the students in relation to the proximate purpose also relate (or do not relate) to the ultimate purpose about how friction facilitates or impedes motion. The teacher uses the word friction and chooses the term resistance as an inter-language, but no continuity is established to the ultimate purposes, which allows the students to use their own chosen colloquial words, the inter-language concept of resistance, and the scientific terms friction and motion to make them continuous in communication and action.

This non-continuous situation is contrasted with the one in the Australian classroom concerning how a teacher introduces the topic of how forces affect objects (an ultimate purpose) with the help of a clay-like material, plasticine. The students were asked to change the form of plasticine (a proximate purpose) and to give the words that they can use to describe what they were doing with the plasticine, such as stretch and roll (colloquial language). Doing this task represents one proximate purpose, which is followed by others. Together with the students, the teacher then sorts their words under the headings of “pull” and “push” (inter-language) and how all their different changes to the plasticine can be understood as “pull” or “push”, which together represent what physicists call “force” (science language). The students and the teacher then work to create diagrams using arrows (semiotic resource) that in a communicative way can help other students to form plasticine to a certain shape (to mediate action through semiotic resources). These arrows at the same time function as a sort of inter-language (arrows that show the direction of force in physics vs. arrows as directions for shaping the plasticine). When the teacher asks the students about the best choice of representation, student 2 highlights its purposefulness:

Teacher: Which one of these representations worked well in explaining what was done?
Student 1: John’s because it showed you exactly what to do. Mine could have ended up anything.
Student 2: It was more visual, you can actually see it is easier to actually see what you did. With the other ones you could make it in different ways.
The semiotic resources are used by the teacher in this Australian study in a way that helps to create continuity because 1) the proximate purposes (shaping plasticine and giving other students instructions about how to give it a specific shape) gives students an activity where they can see an end-in-view, and 2) the semiotic resources are formulated explicitly by the teacher together with the students in such a way as to create continuity between the ends-in-view and the ultimate purpose of teaching students about the concept of force and how it can be represented.

**Significance of Findings**

Students do not learn scientific concepts simply because the teacher adopts an inter-language, but rather the students use their own experiences and a variety of semiotic resources. The use of these meaning-making resources needs to be closely monitored in relation to the continuity it creates to the proximate purposes, ends-in-view, and ultimate purposes of lessons. Hence, teachers can use the two organising purposes as a heuristic to support science learning by planning for and monitoring their continuity in the sequence of classroom experiences of the students.

**STUDY 3: IMPLICATIONS OF A REPRESENTATIONAL PERSPECTIVE FOR ASSESSMENT OF SCIENCE LEARNING**

**Background, Rationale**

As noted by many researchers, and summarized by Osborne and Dillon (2008), current constrained assessment practices in school science often entail rote memorization in an information transfer model that fails to (a) measure the depth of student learning, (b) provide useful feedback to learners, and (c) match the richness of experiences and representational challenges faced by learners in the classroom, and by scientists in research teams. In supporting science education reform, Duschl (2008a, p. 278) argued that students should participate in “the social processes and contexts that shape how knowledge is communicated, represented, argued, and debated”, where activities and tasks “make the students’ thinking visible”. However, the question of effective formative assessment practices that address directly the adequacy and development of students’ representational choices remains under-researched. Hattie and Timperley (2007) and Black and Wiliam (2009), in their recent analyses of effective formative assessment processes, claimed various types of activities, such as sharing success criteria with students, classroom questioning, teachers’ written feedback on student work, peer- and self-assessment by students, and formative use of summative tests, enhance subsequent student test performance. However, these prescriptions also tend to ignore addressing representational challenges students face in learning science concepts.

From previous studies we have identified various pedagogical principles that promote an effective focus on student-generated representations for learning in science (Carolan, Prain & Waldrip, 2008; Prain, Tytler, Waldrip & Hubber, 2009; Hubber, Tyler & Haslam, 2010). These principles suggest that teachers and students need to understand representational conventions and purposes and to assess their clarity and adequacy as evidence of students’ emerging thinking, reasoning processes, and conceptual understanding. By implication, formative feedback from students and teachers needs to focus on timely judgments and guidance about processes or strategies for understanding representational tasks, redress misunderstandings, confusions, ambiguities and omissions. Formative feedback should also
lead to strategies that enable students to self-regulate their next attempt at representation, or integrate multiple representations to show conceptual understanding.

Drawing on this literature, we aimed in this study to: (1) identify formative assessment processes in a science classroom where the teacher focused explicitly on student-generated representations, (2) identify changes, if any, in students’ performance in summative topic testing after experiencing a representation-rich learning environment, and (3) consider the implications of these findings for current theory and practice in formative and summative assessment in learning science.

Methods
Our mixed methods research approach entailed collection and analysis of quantitative and qualitative data using case studies of two Year 8 secondary Australian science classes of like quality in terms of students’ past performance in science, over a period of six months. Topics covered included nutrition, chemical equations, astronomy, particle theory and air pressure, and force. Students in each class participated in diverse interpretations and constructions of representations of science concepts and processes. These included group and whole class talk about different aspects of the topic, interpreting teacher notes and diagrams, re-representing three-dimensional practical activities in two-dimensional formats, making sense of and re-representing video and other resources used to supplement classroom activities, participating in virtual web-based experiments using tables and graphs, and student construction of their own two-dimensional representations of practical investigations. Data sampling and analysis included observation and videotaping of the teachers’ classes, analysis of classroom interactions, teacher and student interviews, examples of students’ work, and analyses of students’ examination scripts. Scripts were analyzed in terms of students’ use of appropriate scientific vocabulary, complexity of sentences in scripts, text readability, number of representational modes used by students in relation to quality of text, and the extent to which modes were integrated through explicit textual ties or embedding.

Results
Analyses of the teachers’ focus in formative assessment processes indicated a shift from assessing the correctness of responses to interpreting their thinking as evident in their representational decisions, revisions, and queries. The teachers no longer assumed that students understood representational conventions or had relevant prior conceptual understanding, but focused on interpreting their accounts of their representations and their reasoning as it became apparent from how they represented and coordinated their emerging ideas. The teachers increasingly focused on assessing students’ knowledge in terms of their capacity to construct, coordinate and judge the adequacy of their representations in terms of their fit for purpose and persuasiveness.

The teachers diagnostically established students’ initial understanding of the concepts of motion, and in subsequent lessons they used formative techniques to explore what was the current state of student understanding and to prompt students to explore alternative perspectives, largely through the use of appropriate questions and judicious use of activities to promote new thinking. This process was influenced by (a) prior understanding of the need to build a coherent account that links properties/behaviour of objects with plausible claims, (b) prior experience with science class methods and the need for accurate measurement of change as the basis for hypothesizing, (c) informal qualitative reasoning around patterns of observed phenomena, and (d) everyday language use of technical terms of topic and everyday ontological accounts of causality. This re-representation work also drew on perceptual
contextual clues, as student attempted to identify key observed aspects of phenomena for investigation, as well as problems/gaps/inconsistencies, and also evaluated the adequacy of their own views compared to what they observed with other groups.

The teachers noted that the focus on representational adequacy had the following effects on their formative assessment practices: (1) their feedback and student discussion were more specific and focused on particular features of the representations. (2) teacher and student feedback focused on the precise meaning (or meanings) as well as limitations of meaning entailed in different representational choices, and (3) they focused far more on students’ intentions and questions than in past approaches.

Analyses of the students’ topic test performance across a range of topics identified the following patterns:
1. Students’ scripts provided more detailed responses than was customary. These responses contained more use of appropriate scientific vocabulary, more words, and the concepts were written about at a higher level of readability.
2. Students were more likely to use diverse representational modes, and to incorporate effective textual ties, such as arrows, captions and labeling to link modes. Students were more likely to realize, in subsequent interviews, the limitation of their representation as a complete answer.
3. During interviews, some students explained that their representations allowed them to show properties and understandings that were difficult to verbalize, and that this use allowed them to communicate key ideas more easily.
4. Students were still partly bound by examination expectations, in that they perceived that teachers gave more weight to written responses than to other representational modes.

Conclusions/Implications
The literature on formative assessment largely draws on cognitive approaches to learning as individualistic information processing, tending to ignore semiotic theories of disciplinary meaning-making, epistemic theories of how science knowledge is produced and validated, and socio-cultural theories of learning through group processes. Our study suggests that a focus on student representational challenges, informed by these perspectives, can provide a practical and valuable focus for formative and summative assessment in this subject. However, our study further suggests that teachers need considerable professional learning support to change to the orientation and strategies proposed in this paper.

Summary of findings
The first paper, ‘Learning science through representational generation/negotiation’, explores the development of a pedagogy based on student generation and negotiation of representations. Based on work over a number of years, with a small number of teachers and key science topics, four key principles of this pedagogy are described and student and teacher data is used to establish the quality of the learning and the issues for teacher change in adopting such a pedagogy. Peirce’s (1931-58), triadic model of meaning making is used to explore the role of representation in learning.

The second paper, ‘Using organising purposes to support semiotic resource use in school science’, uses Dewey’s notion of ‘ends in view’ to explore how the immediate, proximate purposes of science activities might be made continuous with more abstracted, ultimate goals of science learning. A practical epistemological analysis of two classroom sequences was undertaken, drawing on the ideas of Dewey (1931-97) and others to show how both students
and the teacher used semiotic resources based on more proximate purposes, but how one teacher made these continuous to ultimate purposes. The paper explores how we might create continuity between these different levels of purpose in science lessons.

The third paper, ‘Implications of a representational perspective for assessment of science learning’, critiques current perspectives on formative assessment from a representational, pragmatist perspective. It uses case studies of teachers working with lower secondary school students to examine the implications of a representation-intensive pedagogy for both formative and summative assessment, and shows how such a focus can result in more complex student responses on tests, and improved learning. The implications for assessment of this representation-intensive pedagogy are explored.

**Overall Conclusions and Implications**

In this symposium the practical implications of a pragmatist, semiotic perspective on learning is explored in relation to the development of a coherent pedagogy, to the nature of quality learning, to aligning resources to create continuity between proximate and ultimate purposes, and to conceptualizing and enacting improved assessment practices. Across these explorations, which are grounded in video capture studies of real classrooms, the symposium aims to signal ways forward for school science that bring together the epistemic practices of the discipline itself and the learning needs of students. In this, we see the symposium as an important contribution in helping us move beyond traditional ways of looking at science learning and knowing, to offer a coherent account of broader socio-cultural perspectives on learning.

**Discussant: Richard Duschl, Penn State University, USA**

Learning science via engagement in epistemic practices has become a very promising line of research. Significant evidence suggests that engaging pupils in growth-of-knowledge practices such as argumentation, modeling and representation promotes important discourse and reasoning opportunities that facilitate 1) students’ conceptual learning and 2) teachers’ adaptive instruction decision making to guide assessments for learning. Further, when the learning goals build and refine knowledge claims employing arguments, models, and representations, important critique and communication criteria come to the fore. Listening to and examining the talk, models, mechanisms, drawings and visualization help make children’s thinking visible; to themselves, to peers and for purposes of teacher’ instruction-assisted learning. The Australian research program where lessons are infused with copious use of representations with subsequent links to literacy practices is clearly demonstrating a positive impact on science learning and instruction. The application and connections of didactics and curriculum theory by Anna Maj Johanesson and Per-Olf Wickman to help frame the learning progressions basis of the research does so in important and effective ways. In pushing the agenda, I offer up six challenges to the symposium participants and the broader ESERA research community.

**Challenge 1. Extending & Scaling Research in Language & Representation on Learning**

There is a need to consider the communication of ideas and information to learners as well as the coherent sequencing of curriculum and instruction aligned to assessments. A review of the language and labels adopted by researchers reveals a wide almost disturbing use of terms and phases. The first challenge is to establish a common language among researchers where the ambiguity of meanings is minimized. Consider a current sample of associated terms and phrases common among scholarly publications:
1) Curriculum Units as: Learning Progressions, Teaching Sequences, Teaching Experiments, Learning Trajectories, Immersion Units, Inquiry Units, Lessons, Activities;

2) Intertwined Epistemic Products as: Evidence=Models=Theories=Explanations

3) Labels for Learning progressions, such as Lower to Upper Anchors; Proximate to Ultimate Purposes, Intermediate Levels, Messy Middle, Construct Map Levels, Meta-representations, Benchmarks, and

4) Terms for Scientific Products/Practices, such as Modeling, Drawings, Data modeling, Representations, Inscriptions, Visualizations.

Challenge 2. Extending & Scaling Research in Cognitive & Social Psychology

Various perspectives compete on learning. The divide is between scholars who maintain extreme positions regarding cognitive (information processing) and situative (sociocultural constructivism) learning theory perspectives, eschewing the middle ground (c.f., Duffy & Tobias, 2010). The field needs some agreement on models of learning that recognize humans as individual cognitive agents functioning within social networks. Among the set of papers presented in this symposium, there are tensions regarding meanings of learning. Since the mid-1990s research has shown that effective learning environments are based on the following cognitive (CP) and social psychology (SP) precepts (Glaser, 1995):

**Structured Knowledge** (CP) Instruction should develop conceptual structures to support inference & reasoning;

**Prior Knowledge** (CP) Learner intuition is a source of cognitive ability that supports & promotes new learning;

**Metacognition** (CP) Reflection on learning, meaning making & reasoning strategies provides learners a sense of agency;

**Procedural Knowledge in Meaningful Contexts** (CP) Learning information should be connected with its use;

**Social participation and cognition** (SP) Social display of cognitive competence via group dialog helps individuals acquire knowledge and skill;

**Holistic Situation for Learning** (SP) Competence is best developed through cognitive apprenticeship within larger task contexts; and

**Make Thinking Overt** (SP) Design situations in which the thinking of the learner is made apparent and overt to the teacher and to students.

Might we not agree to these or similar foundational precepts and then show how representations and other discourse practices can aid learners to build and refine models and explanations. Where students’ work samples are used as assessments to guide learning and policy decisions, the research and policy communities need to come to agreement on viable models of learning (Gitomer & Duschl, 2007).

Challenge 3. Extending/Scaling Research on Coherence & Resonance in Assessment

Student representations during instruction can provide ‘making thinking visible’ opportunities that teachers can use to guide decisions for adaptive instruction. The established
‘accountability’ agenda of measuring achievement with high stakes tests competes with newer ‘classroom assessments’ agenda of evaluating learning for purposes of guiding/adapting instruction to advance learning. The research on using representations is presently focused on ‘Assessment for Learning’. To address the coherence problem, the research needs to also study the use of representation in the ‘Assessment of Learning’ as well as the delayed and immediate logistics of using representations for ‘Assessments for Learning’ with external and internal audiences.

Challenge 4. Extending & Scaling the Research into Instructional Practices

A long and strong tradition in science education research has focused on conceptual change. Children’s thinking is surprisingly sophisticated in some domains, mirroring adults’ ideas, although lack of key conceptual details have been variously labeled misconceptions, alternative conceptions, and naive conceptions. However, children also have sound intuitions from which productive foundational platforms of learning can arise (Duschl, Schweingruber, Shouse, 2007). The key to conceptual change learning is establishing a coherent sequence of learning accompanied by an alignment of Curriculum–Instruction–Assessment. A recommendation from the research synthesis report Taking Science to School (Duschl, Schweingruber, Shouse, 2007) is to coordinate instruction around learning progressions that, in turn, focus on core science ideas and scientific practices. Tytler and colleagues have begun to make this important transition in the research programme (one I strongly endorse) as seen in their partial list of teaching principles to enact representation use.

Challenge 5. Extending & Scaling the Research in Data Modeling

The symposium papers emphasize the role representations have on concept learning. An important component of science learning no doubt but insufficient if left unconnected to the evidence used to establish the explanatory claims. The current focus is to pursue the goal of ‘using knowledge’ in building and refining models and explanations. Thus, developing scientific practices across the grade span is paramount to learning, communicating and evaluating science knowledge claims. An underrepresented focus in both mathematics and science education is data modeling and the accompanying roles of data, chance, and inference. (Lehrer & Kim, 2009) Mathematizing nature is a central dynamic of science inquiry but an oft-underrepresented part of instruction in science education. The message is that instructional time needs to be given over to students’ engagement in such refined practices as inventing, constructing, and refining 1) measures, 2) units of measures, 3) representations of measurements, 4) models of chance events, and 5) inferences regarding future data gathering and modeling.

In our research (Lehrer & Schauble, 2004; Lehrer, Schauble & Lucas, 2008) we are finding that instruction must involved learners’ with:

(1) Prolonged experience with phenomena,
(2) Posing and revising questions – working over time to make explicit and refine criteria for good questions,
(3) Parsing objects and events into attributes that bear on the question,
(4) Considering/debating means of measuring attributes in ways that support an initial model of the phenomenon (considering the measure properties of those attributes,
(5) Generating/creating data (observing its measure qualities, reliability, etc.
(6) Structuring data (patterns are made, not found),
Interpreting data as evidence – model construction,
Model testing against the original phenomenon & new cases,
Generation/entertainment of alternative models,
Evaluation of model fit, and
Model selection/revision.

The point is that most of the above steps involve types of representations that go well beyond the concept focused drawings that currently characterize the research from the symposium papers. Measurement and data modeling must be central components in science representations precisely because they are central to claims of evidence and explanation.

Challenge 6. Extending/Scaling Research on Attainment of Communities of Practice

A focus of my research beginning with Project SEPIA (Duschl & Gitomer, 1997) and extending to research on argumentation (Duschl & Osborne, 2002) and on inquiry (Duschl & Grandy, 2008) has been the design of learning environments that establish epistemic learning communities (Duschl, 2008; Duschl & Jimenez Aleixandre, 2012). The research on the use of representations in science learning found in this symposium’s papers make important contributions to understanding the design of learning environments. However, much more work needs to be done on the whys to engage children in the production and teachers in the assessment of various contexts for making thinking visible; e.g., drawings, models, mechanisms, stories, explanations, establishing criteria, measurements, data modeling, evaluating chance, and drawing inferences.

References


