DESIGNING EFFECTIVE INSTRUCTIONAL MODELS FOR INCREASING STUDENT ACHIEVEMENT

by

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Designing Effective Instructional Models For Increasing Student Achievement

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ABSTRACT

The challenge of improving the performance of students with diverse needs and abilities has concerned teachers throughout the history of modern education. However, not until the accountability measures instituted by the No Child Left Behind (NCLB) Act of 2001 – requiring disaggregating the results of all subgroups of learners, by ethnicity, socio-economic status, pupil services, and English language proficiency – has this challenge of reaching out to every student that needs attention been brought to the public's focus. This progressive facet of the law has been a positive driving force in Balasubramanian's research agenda. As scholar-teacher, this portfolio dissertation describes Balasubramanian's ongoing efforts to consistently increase student learning and achievement as he continues to work in high-needs secondary schools – schools with large populations of students from low-income, migrant, and international families – by focusing on student motivation, engagement, and cognition. All five studies described here have shown significant normalized gains. These gains demonstrate the increase in standards-based content knowledge of learners across all levels due to specific instructional interventions. The effect sizes of the observed means across all the studies were high.

This abstract accurately represents the content of the candidate's thesis. I recommend its publication.

Signed___________________________

Brent G. Wilson

DEDICATION PAGE

This dissertation is dedicated to my parents Radhakrishnan Balasubramanian and Visalakshi Balasubramanian, my in-laws Maniam Varagoor and Vasantha Maniam for their unconditional support, love, and prayers, and my students who inspire me every day with questions from their inquisitive young minds.

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Chapter 2. Learning by Design: Teachers & Students as Co-Creators of Knowledge. Reprinted with permission from Dr. Kari Kumpulainen, *University of Oulu*, Finland. [Co-author: Brent G. Wilson]

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Chapter 6. Nurturing Teacher Excellence Using the Learn By Design Model (LBDM). Draft of article currently under review for publication in *Principal Leadership*. [Co-authors: Jana L. Frieler and Dr. Elliott Asp]

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INTRODUCTION

"I do not want to be a TN again" said a teacher-leader at Overland High School (Overland) just six hours after training on the *Learn by Design Model* (LBDM) – an evidence-based instructional model to increase student achievement. The teacher-leader was saying she did not want to be a *traditional* teacher who did ***not*** explicitly focus on higher-level literacy skills in her classroom. Another teacher wrote: "I considered the teaching strategies each trainer used and the materials they referenced. I then realized the importance of being in the upper left quadrant in every lesson I teach." These teacher-leaders were referencing the quadrants in the experimental two-way (Teaching x Thinking) factorial design (Figure 1.1) of LBDM, introduced earlier by their trainers.

How did these teachers at Overland become involved in educational research? This dissertation is a report about how these teachers and I are now in the early stages of a systemic school-wide curriculum reform project using LBDM and its required set of intentional and pragmatic instructional interventions to increase student achievement school-wide.

Thinking / Teaching	**E**xplicit Focus on Higher-level Literacy Skills	**N**o Explicit Focus on Higher-level Literacy Skills
Embodied-theory of instruction	**EE** Student Learning & Achievement	**EN** Student Learning & Achievement
Traditional instruction	**TE** Student Learning & Achievement	**TN** Student Learning & Achievement

Figure 1.1 Experimental two-way factorial design

Teachers throughout the modern era have been challenged to improve the performance of students with diverse needs and abilities. The accountability measures instituted by the No Child Left Behind (NCLB) Act of 2001 – requiring disaggregating the results of all subgroups of learners by ethnicity, socio-economic status, pupil services, and English language proficiency – have brought the challenge of reaching out to every student that needs attention back to the public's focus. NCLB is a complex legislation with many impacts and repercussions, some unwelcome to educators and students. The *progressive* facet of NCLB (2002) requires that

> All children have a fair, equal, and significant opportunity to obtain a high-quality education and reach, at a minimum, proficiency on challenging State academic achievement standards and state academic assessments. (p. 1439)

This facet of the law has been a positive driving force in my research. The narrative in the following section offers a personal account of my efforts as scholar-teacher working in two high-needs secondary schools in Colorado to increase student achievement by focusing on student motivation, engagement, and cognition. Then I present the theme and cohering line of inquiry inherent in all the chapters of this portfolio dissertation. The next section describes a conceptual model used for increasing student achievement. After a brief synopsis of each chapter, the penultimate section summarizes the results from my empirical studies. The final section concludes with my reflections and planned further studies.

Journey of Happy Accidents

One way to cope with the mandate to assess and report achievement broken down by subgroups and account for performance of these groups is to claim that achievement for all subgroups is unrealistic without adequate resources and funding. Some schools revise curriculum with a myopic focus only on reading, writing and mathematics. I observed this tendency during my state-wide evaluation of the Colorado Mathematics Engineering Science Achievement (MESA) program (Balasubramanian, 2003) – an after-school program targeted toward disadvantaged minority youth. However, what I also discovered while interviewing MESA advisors was that students participating in activities for an hour after school, doing applied science, engineering and technology projects, were subsequently motivated in their core classes of language arts and mathematics. Prior to that time – even as a scientist myself, amidst a family of engineers – I had not made the connection that the skills necessary to excel in science and engineering necessitated good reading, writing, and mathematics skills. In the words of one MESA advisor:

> Career education, learning excitement, critical thinking and meta-cognition, and increased language skills (crucial for ESL students) [helped my students] aside from the obvious value of increased comprehension in the content areas.

Seeing the MESA students more engaged, teachers in the core classes started asking advisors what they were doing with the students after school. Apparently students who reached elementary and middle schools with limited cognitive skills and few resources at home or community had become less motivated with a narrowed curriculum of reading, writing and mathematics remediation lessons. Yet these same students, when exposed to opportunities afforded through programs like MESA, showed in the words of one MESA advisor, "a remarkable improvement in their language arts, math and science ability." These students were engaged and understood what they were doing.

This understanding of the link between science, engineering and technology projects and literacy/numeracy goals was further reinforced while proctoring the Colorado Student Assessment Program (CSAP) in April 2004. CSAP is a statewide assessment for students in grades three to ten in reading, writing, mathematics and science that provides educators and parents with a snapshot view of what students have learned and achieved each year in school vis-à-vis the Colorado Model Content Standards. The students I supervised were a small group from pupil services (special education) at a high-needs middle school. With nothing better to do during supervision, I happened to glance at the CSAP reading test of a student who was absent. As I started reading the assessment, I started wondering about the skills students needed to succeed in this test. I soon recognized a pattern – students could succeed at large chunks of the test by merely demonstrating their ability *to think* in this mandated exam!

With my interest piqued, I read the mathematics, writing and science tests. Suddenly I recognized a fundamental purpose of school – develop students' reasoning and thinking skills – as they moved from one classroom to another. Could I develop a graphic organizer that might promote teaching *for transfer* – where students learn knowledge and skills in one subject-discipline that they could then master and apply not only within that subject-discipline but also transfer across other subject-disciplines, while learning common reasoning and thinking skills? I developed a graphic organizer and shared it with my colleagues and students at school to break the popular paradigm of thinking within "silos" of individual subject-disciplines (columns in Figure 1.2).

A GRAPHIC ORGANIZER TO FACILITATE SYSTEMIC THINKING ACROSS SUBJECT-DISCIPLINES

READING	WRITING	MATHEMATICS	SOCIAL STUDIES	SCIENCE	TECHNOLOGY
R1 Challenge: Question, Purpose	W1 Challenge: Topic, Purpose, Thesis	M1 Challenge: Problem	SS1 Challenge: Topic, Theme	S1 Challenge: Question, Problem	T1 Challenge: Problem
R2 Skim passage: Connect to background knowledge; Activate schema; Make educated guess using context clues	W2 Pre-write: Brainstorm, Outline, Plan, Web	M2 Identify concepts	SS2 Identify key terms, Vocabulary; Isolate & classify variables	S2 Identify concepts; Make educated guess, Hypothesize	T2 Design brief: Specifications, including timeline
R3 Read passage: Process information; Look for key words, ideas, events; Reason	W3 Write rough draft	M3 Devise problem-solving strategy	SS3 Reason: Observe cause & effect relationships	S3 Reason, Identify cause & effect relationships. Select variables to control	T3 Explore multiple solutions: Select best & creative solution
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
R6 Summarize & synthesize: Check if purpose accomplished; Communicate & justify solution using own words	W6 Share & communicate using final draft	M6 Verify reasonableness of result; Communicate solution	SS6 Summarize & synthesize: Check if purpose accomplished; Communicate; Predict	S6 Verify reasonableness of result; Check if purpose accomplished; Communicate findings of experiment	T6 Reflect on product & process; Modify design; Share & communicate final design

Designed and developed by Nathan Balasubramanian — April 17, 2004

Figure 1.2: Explicitly teaching thinking to promote transfer of learning

Unfortunately, two math and science colleagues who were excited about using the framework in their classrooms left my school to move to other middle and high schools within the district the following year.

In the meantime, I kept pursuing ways to promote students' thinking and reasoning skills. In spring 2005, I encountered another opportunity to collaborate with industry professionals by way of the Colorado MESA office. The Hands-On Optics (HOO), a unique informal science education program funded by the National Science Foundation, was looking for volunteers to pair optics professionals with science teachers in middle schools to excite students about science, technology, engineering and mathematics (STEM) through the world of optics. Although we worked together only for a short time, the discussions with my Optical Resource Volunteer (ORV), Kipp Bauchert, made me realize how meaningful collaborations might be forged between K-12 schools and professionals from industry to make the real-world connections transparent to students. Additionally, I could see the pivotal role and contribution of K-12 institutions in preparing our students with necessary thinking and interpersonal skills to stem the tide against retraining a poorly prepared workforce. These skills would also help *all* students cope with the unique and complex challenges of the 21st century (Bransford et al., 2000), particularly with the "death of distance" due to globalization and the World Wide Web (COSEPUP, 2007). At the same time, reforms would need to be tuned to the SCANS competencies based on job requirements (SCANS, 1993).

Over a lengthy period of classroom experimentation, confirmed by research in conceptual change (Borges & Gilbert, 1999; Carey, 1999; Champagne, Gunstone & Klopfer, 1985; Pintrich, Marx & Boyle, 1993; Posner, Strike, Hewson & Gertzog, 1982; West & Pines, 1985), I have found value in learning activities that are *unsettling* to the established expectations of both resource-deprived and resource-affluent students. Students have a tendency to rush through building activities without much reflection. In science labs this is due to students' preconception of experimentation as a way of *trying* things out instead of *testing* their *ideas* (Bransford & Donovan, 2005). What I have found teaching applied technology, pre-engineering and science classes is that a challenging scenario that violates expectations can produce a "STOP," where students are forced to backtrack and reconsider the situation. Thus a combination of intensely engaging activity and deliberative slow-down time for reflection can promote the learning of higher-level literacy skills (Table 1.1). The unsettling activities are effective in increasing student achievement among all subgroups of students because it challenges students, not only those in the extremes (1.0 and 4.0 GPA students), but also the ones in the middle (2.0 and 3.0 students). This STOP to reflect step has been worked into the LBD Model (Figure 1.3).

The resulting reflection cycle, with the added STOP step especially geared toward secondary students, is a variation on Schön's (1983) reflective cycle of REFLECT → THINK → ACT. I came to believe that sustained practice in this reasoning cycle can help all students become proficient or advanced in CSAP. This link was reinforced in May 2006 as I spent three days with colleagues from around the state in the CSAP Standard Setting - Science meeting to help decide what is "good enough" for 10th-grade students of Colorado. Perusing the high school CSAP tests and speaking with students and colleagues in spring 2007 reaffirmed my conviction that this written assessment is a good measure of our students' ability to reason and think in preparation for college and work – and that students could indeed be trained to succeed at this level of performance.

As a physics scholar-teacher, I am interested in finding meaningful answers to the question, *why is physics worth teaching and learning*? I have been passionate about making physics accessible to *all* students. This passion has helped me move away from the extremes because I learned early in my teaching career in 1989, that focusing on a rigorous, math-based set of algorithms and strategies for teaching physics only helps a few determined individuals survive. Trying to make physics exciting with fun demonstrations still makes it a hit-and-miss opportunity. Instead, a middle road of being intentional and transparent has helped me position physics as an endeavor in developing students' higher-level literacy skills and effective tools for schools – critical thinking, problem solving, mathematical reasoning, inference making and visualization/modeling. In disseminating these five constructs so that students, faculty and parents understand and relate to them, I happily learned in May 2007 that colleagues from other subject-disciplines also easily related to these constructs and this is further described in the chapter on nurturing teacher excellence.

Table 1.1 presents how the five higher-level literacy skills – critical thinking, problem solving, mathematical reasoning, inference-making, and visualization/modeling – are currently defined and targeted across the four core academic subjects; English, mathematics, science and social studies.

Table 1.1. Higher-level Literacy Skills illustrated with sample activities from the four core subjects (English, mathematics, science and social studies)

1. Critical Thinking (CT)

Critical Thinking = Purposeful Reasoning + Reaching Valid Conclusions

Science CT Illustrative Inquiry Scenario

Using only the materials provided, can you make the Piezo Buzzer beep?

- 1 fruit, 1 vegetable, 1 buzzer, 2 coins, 2 galvanized nails and 3 wires

Social Studies CT Example

Now that we have examined the development of justice throughout Middle Eastern history, how would you evaluate justice as it relates to modern government/economic practices/religious systems/social structures in the region?

Math CT Example

Using the theorems of triangles and angle postulates, how will you prove that two triangles are congruent?

English CT Example

Using the criteria we have discussed, examine the poem to determine the *difference* between your analysis and your opinion of the poem.

2. Problem Solving (PS)

Problem Solving = Overcoming Obstacles + Achieving Goals

Science PS Illustrative Inquiry Scenario

Using the choices (tank shell, golf ball, baseball, bowling ball, football, pumpkin, adult human, piano or Buick) provided in the Projectile Motion Simulation (http://phet.colorado.edu/web-pages/index.html)

- Determine the angle at which your launched object hits the target?
- Can you now hit the target by launching it at an angle that is completely different from the original angle?
- What angle should you launch a projectile to make it travel the farthest distance, with and without air resistance?

Social Studies PS Example

Create a Bill of Rights – a set of laws designed to preserve the concept of justice – that would satisfy the desires of all of your citizens for your developing government.

Math PS Example

Use a general problem-solving plan to create a rule for any number (n^{th} term) in a sequence using numerical strategies or manipulative models.

English PS Example

How do authors use *literary elements* to expand the boundaries of reality? Specifically, (a) Explain this with specific reference to the textual evidence in *Night*, and (b) Analyze how these literary elements "*affect*" the reader?

Table 1.1 (Contd.)

3. Mathematical Reasoning (MR)

Mathematical Reasoning = Abstract Concepts + Supporting Results

Science MR Illustrative Inquiry Scenario

• Measure the mass of the six colored containers provided. The containers are filled with some unknown object.
• Look for a pattern among the masses of the six boxes and guess what might be accounting for the change in the mass of these containers.
• Explain (in your results) how this activity might be connected with a topic being studied in class*.

*Students had studies Electric Forces and Fields when they were given this activity to connect it with Millikan's Oil Drop Experiment in Modern Physics.

Social Studies MR Example

Compare at least two modern Middle Eastern countries and make sure that you include relevant statistics from the website www.abc-clio.com in your analysis.

Math MR Example

Can you build the numbers 1 – 20 by using the four basic operations and only four 4's?

English MR Example

Now that you have started reading the *Odyssey*, analyze and explain the parallels between the myths in ancient Greece and the myths in the present day.

4. Inference-Making (IM)

Inference-Making = Logical Reasoning + Informed Decision-Making

Science IM Illustrative Inquiry Scenario

Using only two batteries, two light bulbs and no more than 4 wires:

(i) Demonstrate how both light bulbs can be made to glow. (ii) Demonstrate how both light bulbs might be made to glow at their brightest. Which of these arrangements would you choose to use in the headlights of your car. Why?

Social Studies IM Example

Now that you have gone through various activities to understand the background to the Israeli-Palestinian conflict, as a member of UN think tank, what is your plan to peacefully resolve the current Israeli-Palestinian conflict? As you present your plan, your peers will assess your plan on its merits, including: what they liked about your solution; concerns with your solution; and questions on your proposed solution.

Math IM Example

Use inductive reasoning to make real-life conjectures about how you might survive in an urban city for two-weeks with only $100.00?

English IM Example

Using specific quotes from the Nobel laureate Elie based on Oprah's interview, what can you infer about his internal conflict?

Table 1.1 (Contd.)

5. *Visualization/Modeling* (V/M)

Visualization = Pattern Recognition + Communicating to Diverse Audience

Science V/M Illustrative Inquiry Scenario

Create a multimedia video presentation to illustrate the difference between gravitational and electric potential. *Sample Worked Example*: Concluding Video in http://doers.us/electrostatics.htm

Social Studies V/M Example

What criteria would you use to assess the successful conclusion of the wars in Iraq and Afghanistan?

Math V/M Example

Based on the properties of geometry's undefined terms we have discussed, can you visualize and sketch the intersections of lines and planes?

English V/M Example

Using your knowledge of poetry sensation which we have discussed (e.g., alliteration, iambic pentameter, etc.) to recognize why the author uses this patterns and rhythm to communicate the poem's meaning.

In summary, I have taught science, technology and pre-engineering long enough – and to varied student populations – to know that students can surprise and outperform conventional expectations. Yes, the subject matter is challenging, but students can rise to the task – not just the gifted student, or the privileged student, but even students hiding on the back row or skipping class. Disadvantages attached to various minority groups only serve to heighten the satisfaction when these students succeed.

NCLB mandates that education not be restricted to the elite. My passion for addressing the inequities in learning among critical subgroups – disaggregated by ethnicity, socio-economic status, pupil services, and English language proficiency – was reaffirmed during a chance encounter with the radical constructivist and Professor of Physics at Boise State University, Dewey I. Dykstra in August 2007. Prof. Dykstra has long written about the elitism inherent in physics education and has spoken about his folk theory of physics teaching at international conferences: "Physics teaching is the presentation of the established canon by the established methods *for the benefit of the deserving*" (personal communication, 2007; italics added). These words have stayed in my mind since our conversation. My research agenda is partly an effort to respond to these historic injustices.

I believe there is no better place than Overland to witness and be a part of this history and change. Over the past six years, Overland has undergone major demographic changes. Specifically, the student community has changed from a predominantly Caucasian, middle-class to an international minority-majority school. The student community now has a diverse population from different social, economic, ethnic, and racial backgrounds, with 35.6% identifying themselves as African-American, 35% Caucasian, 22.3% Hispanic, 6.5% Asian, and 0.6% American-Indian. Students from the school represent over 60 countries and speak over 54 different languages at home. In addition to the ethnic diversity and international families, the school now has a poverty rate of 41%. During a reflective activity in the LBDM training, after listening to Muhammad Yunus' story in the 8th habit (Covey, 2004, pp. 6-9), a teacher-leader wrote: "Some of us are convinced that poor people can't learn, or minorities can't learn. Every child needs to have the opportunity to learn and they will." Above all, this is an essential understanding for teachers working in schools with large populations of students from low-income, migrant, and international families. I consider it an honor and privilege to be working in this great school.

Theme and Cohering Line of Inquiry

Throughout this journey of happy accidents, described in the previous section, several questions have guided my inquiry as scholar-teacher in the classroom and serve to tie succeeding chapters together.

How do I as a classroom practitioner motivate and engage all students? Specifically, how do the average normalized gains (Hake, 2007) of the different subgroups (disaggregated on the basis of ethnicity, gender, and pupil services) compare when they are instructed through guided-inquiry hands-on learning?

How do technology-mediated tools impact student learning and achievement? In particular, how do the effect sizes of the different subgroups (disaggregated on the basis of ethnicity, gender, and pupil services) compare with the use of such tools for promoting student learning and achievement?

The core convictions guiding this scholarly inquiry and my classroom instruction have always been:

> Hands-on and minds-on activities that challenge students result in greater student *engagement* and learning for *all* students. Focusing on students' individual ways of thinking (meta-cognition) is a proven best practice that not only promotes *transfer* of learning across subject-disciplines (Bransford & Schwartz, 1999), but also helps increase student achievement of *all* students – the resource-deprived and the resource-affluent.
>
> Well-designed *games and simulations*, with embedded intelligent tutoring systems, which afford *students* opportunities to engage and explore core concepts through inquiry scenarios in a scaffolded learning environment, prior to formal instruction, will result in greater student *motivation* and learning. The educational strengths and possible explanations of why games and simulations are beneficial are described in detail in the fifth chapter.

Certainly, findings from the latest brain research studies on social intelligence (Goleman, 2006) show that the "low road" of engaging and motivating students first is the right way to access the "high road" of developing students' higher-level thinking.

Conceptual Model

Increasing student achievement is a complex endeavor and continues to challenge educators world-wide. The conceptual model discussed here describes how this might be accomplished by teachers and students using a template of activities and protocols for fostering effective teaching and learning. This required set of instructional practices in the classroom is called the *Learn by Design Model.* The model has two components. First, to inspire students, this model uses an embodied theory to provide an explicit template of activities and protocols for teachers to align curriculum, assessment, and instruction. It is a set of doable steps based on current theories of learning and cognition to increase student achievement. The model adopts a *backwards design* approach (Wiggings & McTighe, 1998), the outcomes-oriented approach of identifying the desired learning goals and then working backwards to develop assessments and meaningful learning opportunities to promote student learning and achievement.

Second, to monitor and develop students' higher-level literacy skills (Table 1.1), this model provides an explicit template of activities and protocols that teachers should focus on to build students' higher-level literacy skills. Activity and protocol checklists are used to facilitate students' integrated learning (Linn, Shear, Bell, & Slotta, 1999) and the required explicit teaching will drive student achievement further. Equally important, this

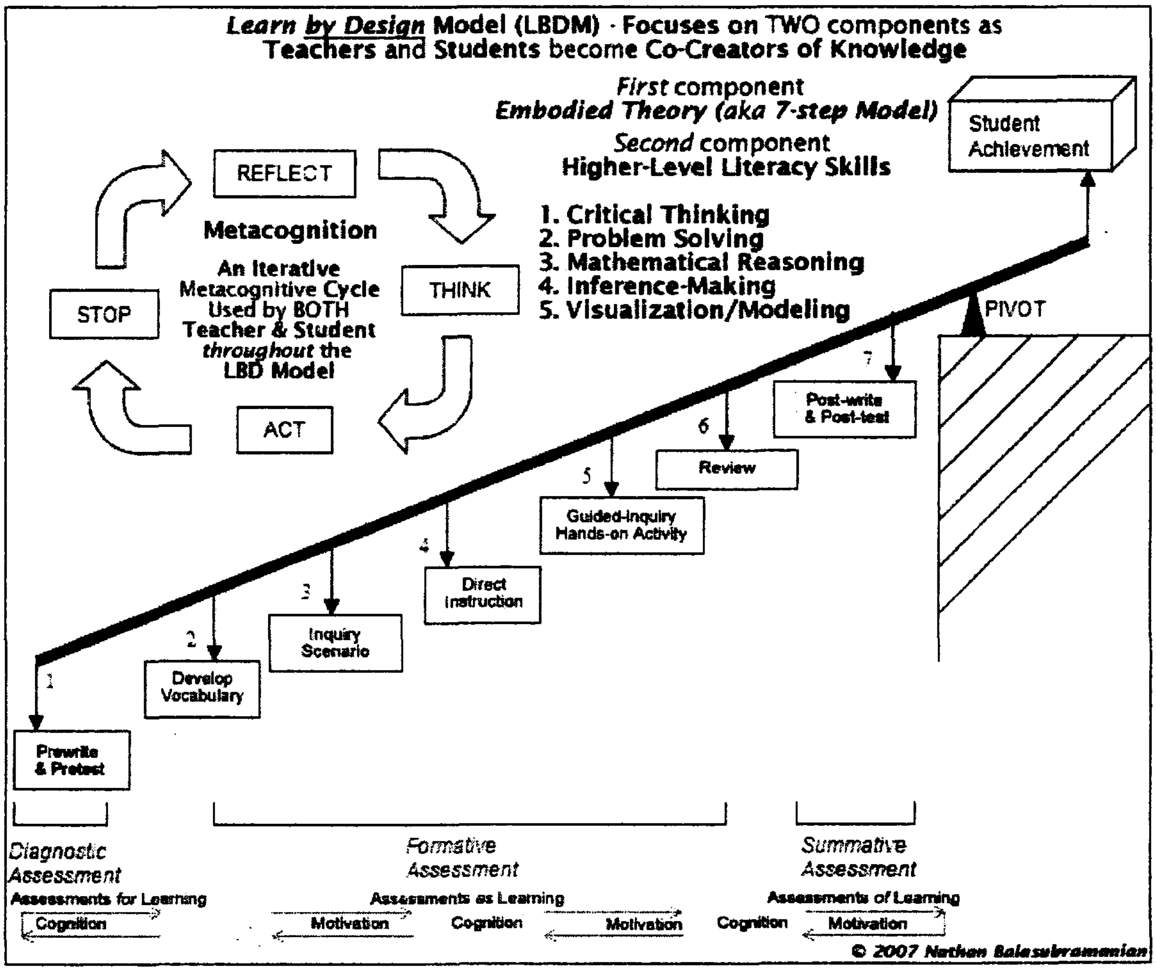


Figure 1.3: Learn by Design Model (LBDM)

model also illustrates how the powerful mission statement of my school district, "To inspire every student to think, to learn, to achieve, and to care," (http://www.cherrycreekschools.org) might be implemented within an underperforming school.

Metaphorically speaking, educators and students have, in the past, tended to focus on techniques to accurately count the number of passes in the "gorilla/basketball" (http://viscog.beckman.uiuc.edu/grafs/demos/15.html) video, instead of focusing on other essential events. This "gorilla/basketball" video shows an incredible experiment designed by two psychologists, Simons and Chabris (1999). The experiment demonstrates that when people pay close attention to an event, however simple, they easily can overlook other important events. When viewers are asked to try and count the number of basketball passes between three students wearing white shirts, without counting the passes made by the three students wearing black shirts, many individuals fail to notice a gorilla passing by. The experiment highlights the sustained blindness and disbelief in dynamic events when people can get lost in small details and forget the big ideas.

The LBDM project described in chapter six is unique and innovative because it explicitly focuses on the gorilla in the room – the embodied theory and higher-level literacy skills (Figure 1.3) – to motivate and engage *all* students and thereby increase student achievement of all levels of students. Additionally, the embodied theory and higher-level literacy skills are structured in ways that build effectively students' confidence and competence. The project's success addresses both equity and excellence. Reducing the achievement gap represents success with equity and raising the academic achievement of all students represents success with excellence.

Summary of Chapters

To set the stage for understanding the results from my empirical studies summarized in the next section, here is a synopsis of the five chapters that follow.

Chapter two, *Learning by Design: Teachers & Students as Co-Creators of Knowledge*, traces the development of the Learn by Design Model as an effective instructional strategy to advance student learning and increase student achievement.

Chapter three, *Innovative Methods of Teaching Science and Engineering in Secondary Schools*, describes how the STRONG (***STR****uctured-scenario* **ON**line **G**ames) Plus Model with the embedded "STRONG" inquiry scenarios might help all students develop good critical thinking, mathematical reasoning, and problem-solving skills.

Chapter four, *Increasing Student Achievement through Meaningful, Authentic Assessment*, elaborates on how learning management systems (LMS) and formative evaluations of students' written and oral communication skills can result in high levels of learning for a large numbers of students.

Chapter five, *Games and Simulations*, elaborates on the educational strengths of games and recommends five guidelines for educational games to be meaningfully integrated into classrooms.

The sixth and final chapter, *Nurturing Teacher Excellence Using the Learn by Design Model*, summarizes an inspiring story of 13 early-adopter teacher-leaders whose commitment, ownership and enthusiasm is driving a school-wide, systemic curriculum-reform initiative with support from the school administration and school district.

Results from my Empirical Studies

The conceptual model discussed earlier is a result of my experimentation with designing workable models of instruction for my guided-inquiry lessons. I believe teaching and learning are part of a complex evolving activity system that can adapt and improve over time through increased student and teacher participation.

This section is an attempt to summarize the results from the five chapters that follow and how I have dealt with numerous day-to-day classroom and institutional challenges since fall 2003 by focusing on student motivation, engagement, and cognition to consistently increase student learning and achievement. They would *make complete sense* after the reader understands the context in which these real-time studies were done (described in the chapters) as students learned challenging content from the state content standards. The reader is strongly encouraged to refer to the individual chapters for further details. Table 1.2 summarizes key findings from these empirical studies and the results illustrate how each study addressed the guiding questions described earlier in section three.

Table 1.2: Summary of key findings from my empirical studies

Subgroups	Chapter 2				Chapter 4		Chapter 5		Chapter 6	
of Students	Direct Instruction		Hands-on Activities		Hands-on Activities		Games and Simulations		Faculty Development	
	<g>	'd'	<g>	'd'	<g>	'd'	<g>	'd'	<g>	'd'
Entire Class	.23 N=56	0.82	.32 N=56	1.4	.44 N=34	1.1	.58 N=40	1.7	0.49 N=13	2.7
Girls	.25 N=29	0.93	.28 N=29	1.2			.68 N=11	3.3		
Caucasian Male	.14 N=13	0.42	.42 N=13	1.8	.41 N=18	0.93	.60 N=18	1.6		
Ethnic Minorities	.24 N=26	1.1	.24 N=26	1.2	.46 N=16	1.2	.57 N=22	1.7		
Pupil Services	.21 N=21	1.0	.23 N=21	1.3						

The normalized gains <g> (Hake, 2007) show the increase in knowledge of the learners due to specific instructional interventions. Although the sample sizes are small in these studies, these gains were statistically significant (at the established 0.05 level). A normalized gain of .23 means that the learners in that specific group gained 23% knowledge because of a particular instructional intervention. The large values of Cohen's 'd' shows the effect sizes of the observed changes in the means in the different studies. Cumulatively, they show that while the effect sizes were high, all subgroups of students learned the challenging standards-based content in my classes.

Reflection and Further Studies

A trend seen in Table 1.2 in section six is the noticeable student gains among all subgroups of students even with partial implementation of the Learn by Design Model (LBDM). These consistent gains are the result of challenging hands-on and minds-on activities that students were engaged in all the empirical studies. As described in section two, the STOP-step, where students are forced to backtrack and reconsider the situation, because of the challenging scenarios distinguishes this model from traditional forms of instruction. Traditional instruction relies on delivering instruction to the middle of the class and differentiating instruction for the extremes. The challenging and unsettling activities, instead, engage and challenge all students simultaneously. Besides, the deliberate focus on students' individual ways of thinking (meta-cognition) rekindles their intentionality and inherent preference for goal-oriented actions. The result, like a high tide that lifts all ships and boats alike to higher levels, all subgroups of students learn and understand at significantly higher levels and consequently student achievement increases. At the time of writing these reflections, Overland is applying for a grant entitled "Overland High School Curriculum Reform and Research Initiative (OHS-CR2I)" for funding through the National Center for Education Research and the Institute of Education Sciences (IES) to continue our work on the LBDM project – the systemic school-wide curriculum reform implementation to enhance student learning in preparation for postsecondary education and workplace readiness – using a three-way (LBDM x Teacher Excellence x Parent Support) factorial design. The three independent variables for the experimental three-way factorial design (Figure 1.4) are a high-quality curriculum developed using LBDM, teacher

2x2x2 Factorial Design for the OHS-CR2I Project

	Parent Support		No Parent Support	
	Teacher Excellence	No Teacher Excellence	Teacher Excellence	No Teacher Excellence
LBDM	***** Student Achievement	*** Student Achievement	**** Student Achievement	** Student Achievement
No LBDM	** Student Achievement	* Student Achievement	* Student Achievement	0 Student Achievement

Figure 1.4. Experimental three-way factorial design for the OHS-CR2I Project

excellence in both instruction (Downey et al., 2004) and classroom management, and parent support. We continue nurturing teacher excellence through our weekly small professional learning community and team meetings for LBDM teachers. We have plans for more faculty professional development sessions at both the high and on-campus middle school with grant funding.

While students continue co-creating knowledge in my classroom, I continue refining and developing instructional interventions to increase students' learning and understanding of physics. I am collaborating with researchers from the University of Pittsburgh and Michigan State University and we submitted an IES grant proposal entitled "An intelligent homework tutor for a variety of high-school physics courses" that will create software to help students learn more as they do their physics homework. Since fall 2007, two of my classes are using *Andes*®, the intelligent homework tutor, and I am comparing student performance in these two classes with a third class (same level and material) using

WebAssign®, another commercial homework help tool. This project will help me continue developing the STRONG Plus Model to gather real-time data on student learning and performance as students hone their higher-level literacy skills (Table 1.1). While *Andes*® would be the backend of STRONG, another collaboration that I forged in summer 2007 with Design Simulations Technologies, Inc. in Michigan, designers of *Working Model 2005*® (aka *Interactive Physics*®), might be another front end for STRONG. Paul Mitiguy, professor of mechanical engineering at Stanford University and lead-developer of *Interactive Physics*® "likes the idea of using LBDM" (personal communication, August 13, 2007) to write instruction and further disseminate *Interactive Physics*® world-wide.

As Project Evaluator for the JumpStart grant in the nine-county WIRED (Workforce Innovation in Regional Economic Development) Initiative awarded to Colorado MESA by the U.S. Department of Labor will help me focus on science, technology, engineering and mathematics (STEM) connections to increase student achievement. I would like to further my science and reading (literacy) research agenda as I continue working with the state office on evaluating the metrics of MESA.

Finally, I wonder if industry could be more actively involved in K-12 education, considering the implications of a poorly trained workforce on our economy. What students learn in school is not only useful for postsecondary education but also essential for their success at work. The concepts in STEM are used on a day-to-day basis by someone in the industry. Establishing partnerships with industry would be mutually beneficial because students would see the real-world connection and industry would not have to spend a billion dollars retraining its workforce.

Looking back, although the *Learn by Design Model* (LBDM) and the *STRONG Plus Model* were developed for use in my classroom, their use by colleagues from other subject-disciplines and continuing to develop the models along multiple fronts is beyond the scope of what I had planned. What the evidence from the empirical studies in this dissertation has shown is that the models can be used by a scholar-teacher in the classroom to increase the achievement of all subgroups of students and the use of models developed by scholar-teachers can become contagious among other teachers. Clearly, using the techniques embedded in the models require innovative teacher-leaders who are willing to contribute their time for planning, reflecting, sharing and collaborating with their peers and students to create engaging technology-mediated learning activities in their classrooms. Early signs seen by the commitment, ownership and enthusiasm of the 13 early-adopter teacher-leaders in implementing LBDM at Overland High School are encouraging.

In summary, this dissertation exposited the LBD model – an evidence-based instructional model to increase student achievement – developed as a response to practical problems faced by two high-needs schools in Colorado to meet NCLB mandates. Models and theories from literature (Table 1.3) were identified and adapted to develop and demonstrate that the LBDM approach to learning and teaching can yield fruitful results in the classroom. While the entire model has been shown to be internally valid, external validity is still pending. A key criterion for successful implementation of the LBD model is how teachers adopt and adapt to change within the context of this framework. As part of future research, extant literature from organization change dynamics (Allen, Strathern, & Baldwin, 2007; Avgerou & McGrath, 2007; James, Mann, & Greasy, 2007; Yeo, 2007) will be adapted to identify the right kind of motivation and incentives to have teachers embrace the LBDM framework and possibly adapt it to share even more greater success stories

Table 1.3. Embodied theory compared with other instructional models

Embodied Theory (aka 7-step model) (Balasubramanian & Wilson, 2007)	Merrill's (2002) *First Principles of Instruction*	BSCS *5E Learning Cycle Model* (Bybee et al., 1989)	*STAR Legacy Learning Cycle Model* (CTG at Vanderbilt (1992)	*How People Learn* (Bransford, 2000) & *Teaching with the Brain in Mind* (Jensen, 1998)
STOP. 1. Pre-writes (Think-writes) and Pretests 2. Building vocabulary	*Activation.* Activate existing domain knowledge of the learner through a scaffolded-progression of inquiry activities that increase in difficulty	*Engage.* Capture student's attention, stimulate their thinking, and help them access their prior knowledge.	*Challenge.* Demonstrate what students should know and be able to do at the end of a module	Use appropriate just-in-time learning stimuli Engage students' *preconceptions* prior to teaching them new concepts
REFLECT. 3. Simulations and simple hands-on inquiry scenarios as challenge	*Demonstration.* Provide investigative structured-inquiry opportunities for the learner and demonstrate knowledge and skill to the learner, when appropriate	*Explore.* Provide opportunities for student's to think, plan, investigate, and organize collected information	*Thoughts.* Students explore what they currently know, including their naïve conceptions about topic	Provide *deep foundational knowledge*
THINK. 4. Direct Instruction		*Explain.* Student's analyze data and information to further their understanding through reflective activities	*Perspectives and Resources.* Students compare their naïve ideas with the thinking of experts & access multiple resources to meet learning objective	Help students make appropriate connections within the context of a *conceptual framework*
ACT. 5. Guided inquiry Hands-on Activity 6. Review 7. Post-writes (Think-writes) and Post-tests Focusing on higher-level literacy skills, using the iterative meta-cognitive cycles of STOP → REFLECT → THINK → ACT, and the leveraged Motivation → Cognition cycles are integral to LBDM	*Application.* Provide project and open-ended inquiry opportunities for the learner to apply the new knowledge and skill	*Extend.* Provide student's opportunities for student's to apply their conceptual understanding to real world scenarios	*Assessment.* Students apply what they know. Feedback from the assessment should further student learning and motivate them to revise and improve their understanding	*Organize knowledge* in ways that facilitate information retrieval and application
	Integration. Provide assessment & sharing opportunities for the learner to integrate this new knowledge & skill into their everyday life	*Evaluate.* Assess student understanding	*Wrap Up.* Final assessment and expert summary	Allow students more opportunities to *define learning goals* and monitor their progress in achieving them

from other classrooms in the school. We also plan to look in to developing a model similar to LBD to incorporate "teachers as change agents in the classroom," and hope to validate the internal and external validity of such an approach to the success of adoption of the LBDM implementation in other classrooms. Observing how the LBD model has become contagious among colleagues at Overland, combined with the challenge, interactivity, and gratification afforded through the purposeful communication within the dedicated professional learning community, I continue reflecting on how research ideas get disseminated and understood by professionals while garnering change. Organizational agility is a developmental process that needs support from the top and growth form the bottom. Despite all the affirmations for the effectiveness of LBDM from students, colleagues, and professionals, I look forward to learning from the pitfalls and perils of leading school-wide initiatives on curriculum reform and change through my lifetime.

Chapter 2

LEARNING BY DESIGN: TEACHERS AND STUDENTS AS CO-CREATORS OF KNOWLEDGE

Abstract

This chapter addresses several concerns of teacher-practitioners as schools strive towards increasing student achievement. It shows how one classroom teacher analyzed students' academic performance, as measured through pre- and post-test scores, online think-writes, product designs, explanations and reflections in a guided-inquiry module, to find that his students made significant gains in specific learning outcomes in science and technology. Using activity theory as a framework, the authors present a conceptual model of teaching and learning as an evolving activity system that adapts and improves over time through increased student and teacher participation. The case study and narrative in this chapter illustrate how learning is enhanced when students are recognized as co-creators of knowledge in the classroom and are able to build on their existing knowledge.

Introduction

The problem of improving performance of students with diverse needs and abilities has concerned teachers throughout the history of modern education. More than fifty years ago the behavioral psychologist B. F. Skinner designed his first "teaching machine" after observing these challenges in his daughter's math class (Skinner, n. d.). Today's classrooms have similar challenges and are more demanding as teachers are expected to reach all subgroups of learners–by ethnicity, socio-economic status, pupil services, and English language proficiency. With limited contact time (Balasubramanian, 2005a; Bransford, 2000; Davis & Farbman, 2004; Popham, 2003), teachers and schools alone seem to be held accountable for helping all students meet established educational standards and perform well on high-stakes assessments.

American classrooms have not fully succeeded in this effort. Results from the 2003 Program for International Student Assessment (PISA) tests showed that 15-year-old students from 27 countries outperformed the United States in mathematics literacy; students from 28 countries outperformed the United States in problem solving (NL, 2005). These results have reopened the debate about what and how students are taught in secondary schools in the United States (Balasubramanian, 2004).

Here is a report of how one secondary school (Grade 6–Grade 12) classroom teacher has coped with these challenges by co-opting technology as an aid since December 2000, and consequently improved student performance in his classes. In sections three and four, we assume Nathan's voice as he provides a practitioner's perspective on efforts to help a diverse range of learners reach high educational standards in his science and pre-engineering classes. Overall, the research is a collaborative effort between Nathan and Brent, with Brent in an advisory role providing scholarly leadership, and Nathan in the classroom trenches solving problems and building successful designs for instruction.

Conceptual Model

In this section we provide a conceptual frame for viewing the activities of Nathan and his students. In the next section, Nathan traces the development of his ideas about teaching and their translation into a workable method for guided-inquiry lessons, which he terms the teacher's embodied theory – that is, theory embodied by a template of specific practices in the classroom. The simple model below illustrates how a teacher's embodied theory can be combined with a core set of tools – in this case a course management system and related Web 2.0 tools – to create a meaningful learning environment for students (see Figure 1).

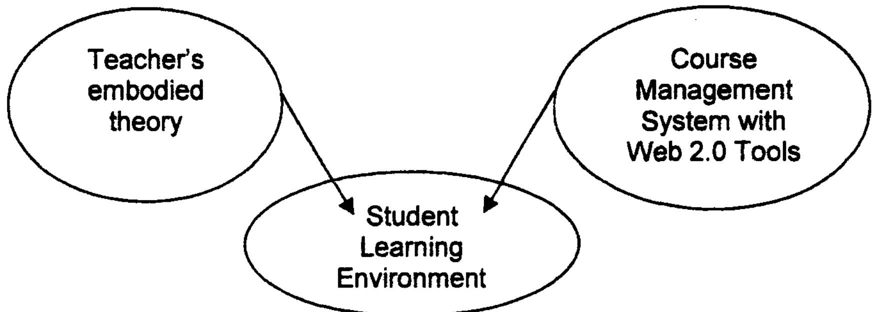


Fig. 1. Creating meaningful technology-mediated learning environments

Psychology-based learning theory can clarify how individuals process information, form and revise schemas, and develop skills and knowledge (e.g., Driscoll, 2005). *Activity theory* moves beyond individual cognition to see classroom interactions in a more objective way – as a set of nested activities within an overall system meant to pursue educational outcomes (Kuutti, 1996). Activity theory, growing out of the work of Soviet psychologist Lev Vygotsky, views learning as the inevitable result of intentional activity over time. Activity *systems* are composed of individual agents or "subjects" (teacher and students), each pursuing objects (learning goals, or more often, performance goals related to an activity). Teachers and students make use of tools (technologies but also a whole host of other tools and resources). They collaborate within a specific set of rules or conventions that dictate meaningful interactions – including some division of labor, particularly between teacher and students, but also between students, especially in working teams.

Michael Cole and Yrjo Engeström pioneered the basic analysis of an activity in activity theory (cited by Bellamy, 1996). Their ideas are widely used for understanding human-computer interactions, workgroup processes, and learning communities. Fig. 2 represents an activity analysis applied to developing "higher literacy skills" (see section 3.2) in K-12 students (adapted from Bellamy, 1996, p. 126).

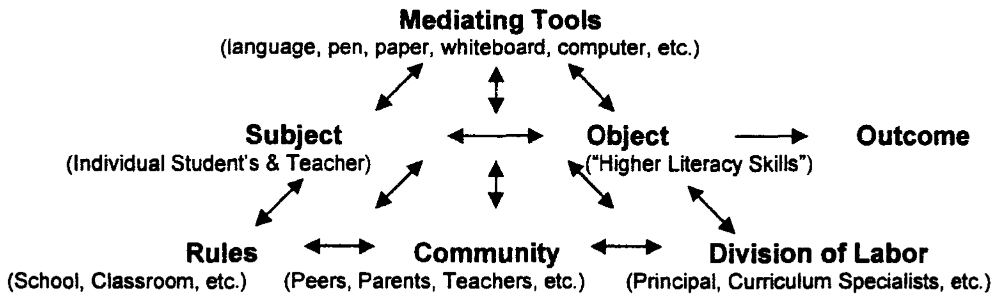


Fig. 2 Cole and Engeström's activity theory framework (adapted from Bellamy, 1996, p. 126).

The basic activity system may be defined as the entire class or a working team within the classroom, using tools and adhering to established rules and community norms to pursue objects of value. The activity leads to learning outcomes, whether intended by the curriculum or sometimes independent of a curriculum (Lompscher, 1999).

An alternate model of Fig. 1 using activity theory (Fig. 2) as a framework, illustrated in Fig. 3, reflects classroom reality. In this model, teaching and learning are part of a complex evolving activity system that adapts and improves over time through increased student and teacher participation.

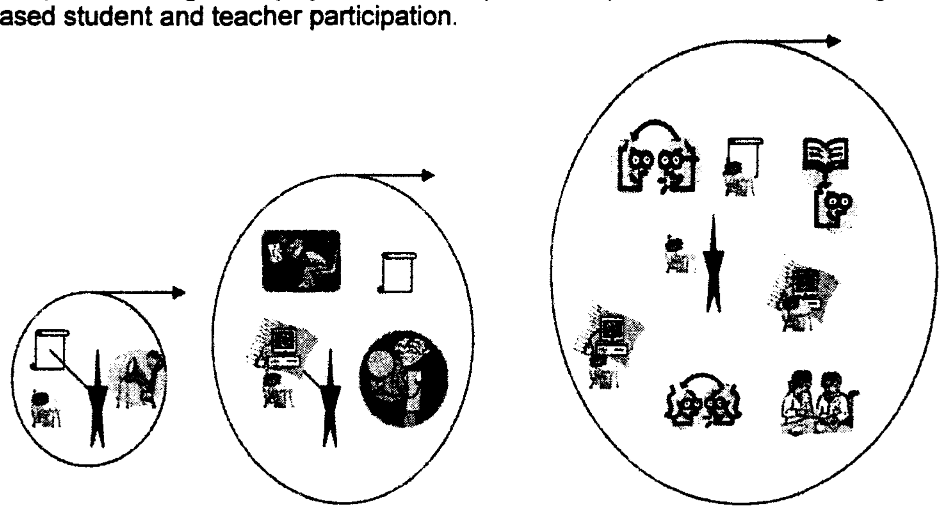


Fig 3. Student learning environment as an evolving activity system

This figure highlights the bounded activity system typical of classrooms and how that system takes shape over time. The classroom and its corresponding online environment contain the basic elements of an activity system, including a guiding set of learning goals and objects for activity, tools and resources, division of labor, and a sense of community. The technology-based course management system and websites house the artifacts of activity, namely, the learning resources developed by the instructor, students, and the outside world.

Through an activity-theory lens, we see the central tenet of activity and people's use of tools in pursuit of goals. The learning that happens in Nathan's classes (described in sections three and four) is the result of complex, group-based, intentional activity, using available tools and resources and following established rules and roles for interaction.

Nathan's Journey – A Case Study

Opportunity

For 17 years, I have taught physics, applied technology and pre-engineering in middle and high schools across three continents. Since emigrating to the United States four years ago, I have immersed myself in two full-time professional responsibilities. First, I had started a doctoral program in educational leadership and innovation in fall 2002 at the University of Colorado at Denver and Health Sciences Center. Second, I had taught applied technology and pre-engineering at a middle school for three years, and now teach physics and physics engineering technology at a high school in Colorado. Both schools are considered "high-needs" because they have a large population of students from low-income migrant families and the schools' overall academic performances were "average" in 2004-2005 according to the federal School Accountability Reports (CDE, 2006). I have viewed these school environments as exciting professional opportunities – their "average" performance providing a correspondingly greater potential for improving performance.

"Higher Literacy Skills"

While interviewing students for my master's thesis (Balasubramanian, 2002) and preparing a presentation for the first Teachers-Teach-Teachers workshop at Emirates International School in Dubai, United Arab Emirates, in fall 2000, I recognized the need for making classroom resources available online for students and parents. In December 2000, I designed my first website (http://www.innathansworld.com/). This website includes extensive resources on various topics that I am passionate about, including physics, career development, and study skills. While this website afforded an opportunity to present students and their parents with up-to-the-minute curriculum information and help on physics, I recognized for the first time how few resources were available to document my effective classroom practices over the previous eleven years.

In fall 2000, I also wondered about the real purpose of teaching physics to secondary school students. Clearly, it had to be beyond helping these students be successful in their International Baccalaureate (IB) and International General Certificate of Secondary Education (IGCSE) physics examinations. I was really interested in developing students' critical thinking, mathematical reasoning, inference-making and creative problem-solving skills, what I consider "higher literacy skills" that would sustain students' lifelong learning, regardless of the career they choose. In discussions on ITForum (2003), I explored some ideas for developing enduring "higher literacy skills" by promoting deliberate reflective, critical and breakthrough thinking in our classrooms. I proposed integrating conceptual physics with career development to make learning meaningful to the students. I now know that focusing on applied science, technology and pre-engineering education in K-12 can do much to help develop students' "higher literacy skills" and enhance their career options.

Acknowledging the importance of developing students' "higher literacy skills" through technology, the International Baccalaureate Organization (IBO, 2000) concluded:

> Schools' technology courses should integrate theory and practice, including much that is scientific, ethical, mathematical, graphical, cultural, aesthetic and historical. They should encourage students to explore the synthesis of ideas and practices, and the effects of technology on societies and environments . . . (p. 9)

These conclusions have been validated by the 90% of K-12 teachers surveyed by the American Society for Engineering Education (Douglas et al., 2004) who agreed with the statements: "Understanding more about engineering can help me become a better teacher; a basic understanding of engineering is important for understanding the world around us; engineering can be a way to help teach students about business; and engineering can be a way to help teach students history" (pp. 8-10). Clearly, pre-engineering education in K-12 is supportive and not conflicting with a renewed emphasis on core academic subjects in schools.

Course Management Systems

In spite of my heavy Web use, it was not until fall 2005, when I first had access to a free course management system (CMS), that I started consistently monitoring and using students' diagnostic, formative, and summative assessments (see Fig. 5) in my classes to create a learning repository and critical mass of authentic classroom learning materials. Some of these resources have been recently featured in an educational technology magazine (Scrogan, 2006).

Course management systems (CMS) are resource-sharing environments meant to support delivery of courses from a distance. Examples are BlackBoard®, Moodle®, and FirstClass®. Services typically supported include document sharing, discussion forums, multimedia presentations, games and simulations, assessments, and grade management. In spite of some criticism concerning their embedded ideologies (e.g., Rose, 2004), CMS have proven useful supports for classroom-based, blended, and online instruction (Wilson et al., 2006).

This has proven true in my case. Throughout the 2005-06 school year, I used Schoolfusion® – a commercial course management systems effectively in my classroom to

- Monitor and manage middle-school students' work and provide them immediate feedback
- Collect real-time data on students' understanding of science and engineering concepts
- Use the information gathered to guide subsequent instruction

My students accessed these online resources while engaged in inquiry-learning activities. An analysis of students' academic performance, as measured through pre- and post-test scores, online think-writes, product designs, explanations and reflections, showed that these students made significant gains on target learning outcomes in science and technology (see Balasubramanian, 2006a).

Popham (2003) noted that the target learning outcomes handed down by the states and districts are "often less clear than teachers need them to be for the purpose of day-to-day instructional planning" (p. 6). In the following section, I illustrate how I used 41 target learning outcomes from the state science standards (Balasubramanian, 2005b) to design and develop a guided-inquiry module (Balasubramanian, 2006b). The module:

(a) presents water filtration and the associated concepts in an engaging way to middle school students
(b) reviews the water (hydrologic) cycle and related vocabulary with students
(c) provides students an opportunity to design and build a water filter using only activated carbon, sand, gravel, cotton, plastic cup, wood structural supports, and hot glue
(d) empowers students to test their filtered water for
- conductivity (remove conducting particles so electricity cannot pass),
- pH (neutralize pH to make it ~ 7 for a basic solution of salt and baking soda in water),
- turbidity (clean dirty water with tea, vinegar and coffee grounds), and
- flow rate (captured filter water should have a flow rate greater than 2 ml/s).

Even as students learn extensive content from the science standards through the water filter project, the embodied theory (section 3.4.3) provides a roadmap for designing guided-inquiry lessons that engage secondary school students. More importantly, these lessons focus on developing students' "higher literacy skills" and prepare them for their standardized tests in reading, writing, math, and science. Finally, the module empowers students by providing them valuable skills for lifelong learning. Implementation of this guided-inquiry module led to significant increases in student achievement for all subgroups of learners in spring 2006.

Embodied Theory behind Student Achievement

To foster a nurturing learning environment and student-centered instruction in my science and technology classrooms, I have students work in teams on authentic and challenging, yet fun problems. By facilitating these activities in the classroom and reflecting on my own learning, I recognize the importance of both motivational and cognitive elements in this adaptive process (Balasubramanian, Wilson & Cios, 2005; Balasubramanian & Wilson, 2006). Motivation in particular is a key for many students – one that is sometimes neglected in the compulsory educational systems now in place. The educational theories I encountered in my doctoral program are both embedded and *embodied* within guided-inquiry modules. The modules are a product of these learning theories, combined with my best creative thinking about how to embody and apply these ideas in real-life classrooms. Finally, a significant element of serendipity enters as students encounter challenges and learning materials – and respond to them thoughtfully. To some extent the modules are a product of negotiation and conversation with constituents – similar to the idea of design-based research that is increasingly popular in the literature (The Design-based Research Collective, 2003). Indeed I consider students to be my collaborators in designing effective learning experiences for them. The sections below give more detail about the water-filtration module and its conceptual basis.

Motivating students through a token "microeconomy."

Helping secondary school students understand and be excited about science and engineering can be challenging, partly due to negative experiences many have already had in science classrooms. After presenting students with some initial challenging activities as a springboard to capture their attention, like moving a ping-pong ball from one beaker to another without touching either beaker (Movie #5, Balasubramanian, 2006c), I explain that science is a systematic inquiry directed toward an understanding of natural systems, which in turn creates new knowledge. The essence of "science" is not so much what the subject of the inquiry is, but in how the inquiry is carried out. A complete science education includes learning the processes, themes, principles, and tools of science. Technology and science are closely related. You can unlock the power of technology when you understand the science behind it. You can find out about new technology when you explore the frontiers of science. Engineering, on the other hand, requires the careful use of limited resources for solving problems in creative ways using science and technology. Besides, access to resources is always a challenge at high needs secondary schools. Although the thinking of scientists, engineers and technologists are not so stereotypical, I use Gilbert's (1978) synthesis of science and engineering to highlight two distinct approaches to problem-solving (Fig. 4).

Thinking like a Scientist	Thinking like an Engineer
Approaches nature with humility, for there is so much we do not know – we are surrounded by a vast sea of ignorance	Approaches nature with certainty, because there is so much we know that we have not applied – we are surrounded by a vast sea of intelligence
Is content to find out what the world is like as it is	Is intent on remaking the world
Has a well-developed methodology, and will do wherever it leads	Knows precisely where to go, and will use any methodology to get there
Makes no value judgment of nature – it is what it is	Begins with value judgment of nature – and seeks to create changes that people will value
Seeks knowledge as an end, valuable for its own sake; and worth great expenditures to gain it	Seeks knowledge as a costly means that should be applied efficiently if the costs are not to detract from the valuable ends

Fig. 4 Indicators of how scientist's and engineer's think

To *motivate* secondary school students and sustain their full interest and engagement throughout the learning process, I have used fake money for students to spend on supplies since fall 2004 in all my classes, after accidentally discovering its effectiveness in also motivating students. These token "microeconomy" dollars are not only an incentive mirroring choices and constraints in the real world, but the money also provides students both individually and collectively constant, immediate, and objective feedback on their performance in each class. The use of dollars challenges them to become creative problem solvers who are trying to maximize their limited resources. Before fall 2004, I talked to students about using resources wisely at the beginning of each school year and before each project. However, it was not very effective. In fact, when students were building air racers with railroad board paper in fall 2004, they used both paper and glue sticks recklessly. In just one class, students would consume one packet of 24 hot glue sticks. However, from the second week, when I decided that students had to pay five "dollars" to buy a glue stick, they suddenly became very responsible and used each stick almost to the last bit before they bought another. This serendipitous discovery was an eye-opener for me, as I no longer have to walk around monitoring resource use in my classes.

Here is how the system is presently implemented. Students start each year/semester/quarter with seed money of $50. Subsequently, they earn money in their classes through their active participation (Balasubramanian, 2005c) and then in turn buy all the materials or lease tools used in the classroom (like hot glue sticks, foam boards, cardboard, railroad board, string, marbles, straws, glue, x-acto knives, glue guns, laptops, probe-ware and so on). These resources cost varying amounts, from $ 1 - $200, and students use them to build and test their creations in their classes.

The monetary system of earning and trading with money has grown beyond the physical resources. The "microeconomy" is now tied in with students acting as consultants, earning royalties from patenting their prototypes, etc. Enjoying the opportunities afforded with money – or borrowing money – in a few cases, from Good Bank Inc., (if they had good credit history) or the alternate Shark Loans Inc. – coupled with the social capital they earn (green "I helped" card – or red "I asked for pointers" card) has been fascinating in its dynamic and its power (Balasubramanian, 2005c). In particular, observing a handful of students borrowing money from my loan shark company because of their poor credit history (of classroom behavior), when they ran out of money, was interesting. These students are desperate to earn and return the money at the earliest to avoid hefty interest payment (20% per week). It makes me wonder if the statistic of more individuals declaring bankruptcy in the United States than the numbers graduating from college (Godfrey et al., 2006) could not easily be reversed if more teachers instituted a "microeconomy" model of classroom management in their secondary school classrooms. Besides, the social capital component helps more students move beyond a mercenary approach to a more give-and-take collaborative approach afforded through meaningful interactions in the classroom. These goals of collaboration and empowerment stand in contrast to some uses of token economies, which place more emphasis on behavioral control.

The way in which students, colleagues and parents have resonated with this token economy amazes me. Moreover, the instantaneous feedback students receive, its highly contextual nature, and ability to support over a dozen interactions a minute during teacher-led instruction – all of these things make it a highly motivating classroom management strategy. With a concrete number for processing their learning gains, students easily recognize where they started (in $) every class and how far they have reached (in $) at the end of each class.

In fall 2005 I started the school year with the idea of studying the impact of monetary monitoring on resource utilization and student performance in two of my applied technology block classes (90 minutes each). One class served as a control group where students did not use monetary monitoring and got whatever they wanted. The other class was the experimental group – they had to buy their classroom resources. I presented both groups with the same problem – build a tallest free standing structure that is wind resistant and resembles a real building using only paper clips and straws (Movie #14, Balasubramanian, 2006c).

I abandoned the study after just the first week because students in the experimental group were careful with the use of resources and came up with elegant designs. They had to pay $2 for each straw and $10 for each paper clip. Conversely, the control-group students, however, nonchalantly depleted these resources. Specifically, while students in the experimental group barely used one box of paper clips (100 count/box) and one box of straws (100 count/box) in two classes, students in the control group used over seven boxes of paper clips (over 700) and four-and-a-half boxes of straws (over 450) in the same time.

Beginning fall 2006, I moved to teach physics and physics engineering technology at a high-needs high school in Colorado. In this school, again, the juniors and seniors, and their parents, have resonated with the "microeconomy" model, just like the earlier middle-school students and their parents. These students also use their resources carefully while creating elegant and well thought out designs and experiments because they have to buy and lease their classroom resources.

Bloom's revised taxonomy and levels of thinking.

When I asked middle-school students why and what they liked about hands-on activities, I heard several fascinating perceptions. One group said they liked "doing it, figuring out how it works." Others said: "Putting stuff together was easy; don't have to think as much; don't have to write as much; and just have to pay attention instead of having to read a lot of stuff." These same students however thought hands-on activities were sometimes difficult. They added:

> Building it might sometimes be hard because you have it the wrong way; write-ups and explanations after the hands-on are sometimes hard; not knowing how to solve a problem, thinking about it, measuring it right; making choices, reading a blueprint, putting it together; sometimes it is frustrating because you can't figure it out; sometimes your team disagrees about doing things and it's majority; not knowing how to put things together; and remembering all the stuff sometimes like in a digital multimeter.

As teachers, we know that organizing hands-on activities can be challenging because these activities require extensive planning, time commitment, organization, and modified teaching strategies. These challenges are compounded by other constraints in the classroom, like resolving group dynamics when working in teams, participating effectively during individual teams' discussions and building activities (with 7 – 10 teams, typically in each class), promoting greater social collaboration within and between teams, and coping with students' "been there, done that" attitude that hinders their learning (Balasubramanian, Wilson, & Cios, 2005). In spite of these obstacles, I use hands-on activities extensively in my classes as culminating activities because even as students build and test their creations or improve their product's performance, they spontaneously generate interesting questions. As the subject-matter expert in the classroom, it becomes much easier for me to seize these teachable moments and help my students think through their designs, carry out their investigations, and answer their own questions.

Hands-on activities, as valuable as they are, must be connected to formal terms and the established content of the science curriculum. Recognizing this, I embraced a revised two-dimensional Bloom's Taxonomy (Anderson & Krathwohl, 2001) to plan and organize the cognitive elements of my instruction. I framed the learning outcomes in such a way that students could easily see the transition from simple to complex levels of thinking for the different projects. For the filter project, even as students design, build and test their water filters, they discovered the answers to over 37 leading questions in a revised two-dimensional Bloom's Taxonomy (Balasubramanian, 2005b).

The two-dimensional framework also gave me an opportunity to present the learning outcomes using a medals-podium analogy. Although the fundamental intent was to have all students assume greater responsibility for what they learn and win, I believed that even when students demonstrated simple forms of thinking, like remembering factual knowledge, their thinking must be recognized with a bronze medal. The farther and deeper students were willing to think, the more creative and metacognitive they became, and consequently their thinking and actions must be recognized with a gold medal. While the intent was to have more students be reflective and creative "gold medal" winners, the structure provided a hierarchy for those learners who were predisposed towards linear and sequential thinking. This kind of epistemological development, helping students understand the value of creative and higher-order thinking, is a valuable learning outcome in its own right.

Embodied theory revisited.

The active "doing" aspect of inquiry activities motivated several middle-school students who talked about "putting stuff together" being "easy." Others suggested that "you don't have to think as much" when doing hands-on activities. The same students were quick to point out, though, that building was "sometimes hard" and "frustrating" because, when they had a problem and "couldn't figure it out," they had to think about it. Clearly, hands-on activities were highly motivating for these middle-school students but were sometimes cognitively challenging too – even for students preconditioned to avoid thinking whenever possible. Now could I balance the two – motivation and cognition – to make learning engaging for these students and consequently increase their conceptual understanding? This question and the updated Gilbert's Behavior Engineering Model (Chevalier, 2003) continue to drive the embodied theory for increasing student achievement (see Figure 5).

This see-saw analogy is intended to show the need for both cognitive and motivational elements – and that motivational elements seem to have a significantly greater leverage than the cognitive elements. Further, the embedded four-step reasoning process becomes a cycle as students' actions turn back into reflections.

Middle-school students have a natural tendency for just completing activities without reflection. To extend Schön's (1983) idea of "reflection-in-action," I added the "stop" before "reflect" in the conceptual framework to add an element of cognitive dissonance, anticipation and intentionality to students' learning. I wanted to break their rhythm and force reflection at the outset. In an effort to uncover mistaken preconceptions, I begin by asking students to respond to a hypothetical scenario and question (Balasubramanian, 2006e) – similar to a story problem about the content.

Students' responses to these think-writes offer insights about their background knowledge. The built-in feedback in the pretest then gives them an opportunity to find out what they know and do not know. Having activated their background knowledge with my diagnostic assessments, students then access an online crossword (Balasubramanian, 2006d) to learn the essential vocabulary in a game-like environment.

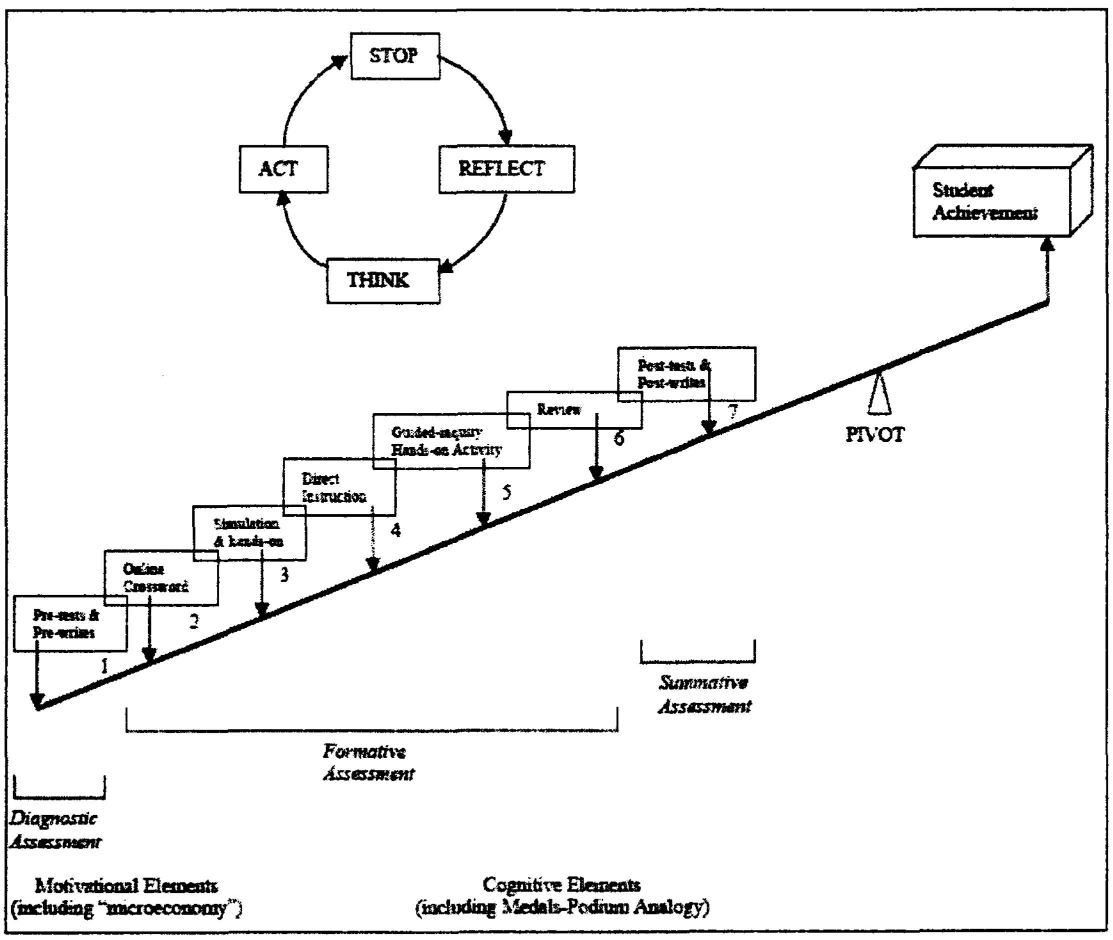


Fig. 5 Embodied theory for increasing student achievement

In my initial design, I did not provide a paper handout. However, at the high school, one student suggested that she would benefit from a paper version of the essential vocabulary in her kinematics module. Consequently, I started using a paper handout to supplement the online crosswords. While using a paper handout that contains all the clues for the crossword, students quickly learn the essential vocabulary while trying to achieve their highest percentage scores. I have had no restrictions on the number of times they may attempt the online crossword, either at school or at home. The more they practice and demonstrate their mastery, the greater their monetary gains. The "microeconomy" stimulates them to try to do their best and earn plenty of dollars before they are presented their next challenge. Students have to solve, using a simulation and/or a small hands-on activity, a simple problem. For the filter-project, students have to arrange six containers, each containing anthracite, fine sand, garnet gravel, garnet sand, gravel, and rocks, in the correct order in which they are arranged in a real filter at the water treatment plant. Then they write down their reasons for their arrangement using both photographs and the actual samples. Through this activity, students are introduced to two concepts: weight and density. And again, their writing offers "a good deal of insight into their understanding, revealing if they are on the mark or conceptualizing something very differently" (Popham, 2003, p. 88).

By this time, most students have found a clear purpose: to look, listen, and learn the concepts I then present through direct instruction. By *direct instruction*, I mean teaching students explicitly how and why things work by telling them. To give them adequate opportunities to review the resources presented during direct instruction, I use an online PowerPoint® slide show and movies of students explaining the tests for the filter-project (Balasubramanian, 2006f). In some classes where I have a prescribed textbook, students review the material with their textbook, my concept map designed with Inspiration®, follow-up homework, and mini classroom quizzes.

Once students have this rudimentary understanding, I present their final challenge as a guided-inquiry, hands-on lab activity. By *guided-inquiry hands-on activity*, I mean helping students learn by doing, including asking them questions, identifying questions to investigate (different from simply answering questions), thinking about them, designing investigations, conducting investigations, and finally formulating and communicating their conclusions in a structured, challenging and goal-oriented environment. For the filter project, students have to design a water filter using only activated carbon, sand, gravel, cotton, plastic cups, wood structural supports, and hot glue to neutralize pH, reduce turbidity, remove conducting particles, and capture the filtered water. After drawing their designs and planning how much material they would buy, students have to purchase the material for building their teacher-approved designs.

The guided-inquiry hands-on activity, followed by tests of students' designs and evaluation by their peers, leads to deeper understanding of the underlying concepts. According to Perkins (1998), students' flexibility in thinking and performing hands-on activities, beyond the rote and the routine, is one metric for measuring their deep understanding. The results of students' tests of their water filters showed several students asking more questions (Balasubramanian, 2006f), making modifications to their designs and undertaking more investigations. Finally, when they have all had a chance to build, test, modify, and test their designs, as a class we review the concepts that we set out to learn in the two-dimensional Bloom's taxonomy (Balasubramanian, 2005b). Students then take their post-tests to complete the module. The individualized feedback received via the "microeconomy" also keeps them motivated along the way. This 7-step process (illustrated in Fig. 5), I have found, results in significant learning gains for all subgroups of students in my classes. In the following section we see how inquiry activities, including some unforeseen by the instructor, led to substantial learning gains for students.

Results from a Pilot Study in Nathan's Class

Facilitation, Teachable Moments and Media

Several researchers (Balasubramanian, Wilson, & Cios, 2005; Yeo, Loss, Zadnik, Harrison, & Treagust, 2004) have observed that hands-on inquiry learning without domain knowledge merely entertains students and results in their inadequate conceptual understanding. Many resource-deprived students reach schools with limited cognitive skills and are consequently less motivated. Wilson (1997) observed that direct instruction to impart domain knowledge in sterile learning environments left students unenlightened and unable to see its real-world relevance. The intentional, technology-mediated "stops" thrust on students as diagnostic assessment (pretests, pre-writes, online crossword) and direct instruction (movies, PowerPoint® instruction, and concept maps designed with Inspiration®) have served as checkpoints for reflection. The periodic stops afford students more time and opportunity to access, process, review, and utilize these resources both in and outside the classroom.

However, the real fun begins, for both the students and teacher, when students actually design and engage in hands-on learning activities. For the materials module, students designed and built their water filters by using only activated carbon, sand, gravel, cotton, plastic cup, wood structural supports, and hot glue. When they tested their filters, they spontaneously started asking questions: "How do you design a filter to get a better flow rate? Does the amount of sand affect the flow rate? Does the order of the layers make a difference for filtration and flow rate? Did compressing the cotton make a difference? How many tests do you have to pass to drink the water?" and on and on (Balasubramanian, 2006e). These spontaneously generated questions are major indicators of schemas in revision. As some sixth graders reflected, "most people passed three of the four tests and none of the people passed the turbidity test with the laser." Students' passion for designing filters that could pass all four tests (conductivity, pH, turbidity, and flow rate) was fascinating and led to a remarkable investigation involving measurement, unit conversions, hypotheses testing, and density. The teachable moment serendipitously surfaced when students wanted to know how they could "pass" the turbidity test. This gave me an opportunity to highlight sand's adsorbing and absorbing abilities.

The supplementary activity started one day when I asked a sixth grade student to bring a piece of sponge (used to remove flux and excess solder in a soldering iron) from the tool room at the back of my class to illustrate absorption. She brought one along and I then asked the class, "What would happen to this sponge if we soak it in water?" They said it would become bigger and heavier because the sponge absorbs the water. They visually and physically verified their hypothesis by soaking it in running water. However, one student was skeptical and asked "How do you know the sponge become bigger when its wet then its dry? [*sic*]" This was a legitimate question and we had not been diligent enough to record the dimensions or masses of the dry and wet sponge. Thinking nonchalantly that I could resolve it by bringing another piece of dry sponge from the back of the class, I asked the student to bring another piece of sponge. However, when she could not find one, I had to bring a "compressed" sponge from a new soldering iron. Just then, another student had a new question: "Which would be denser, the dry or the wet sponge?" Acknowledging that it was a great question, I went on to explain how density depends on both mass and volume and then guided them through the design of an experiment for investigating the density of dry and wet sponge. We made our educated guesses about the densities of the wet and dry sponge before experimenting and students demonstrated their measuring skills with a ruler and a triple beam balance. When we started recording and calculating the density with our measurements, the problem became interesting.

Initially, almost the entire class and I guessed that the wet sponge would be denser. Our reasoning was that the change in mass was more likely to outweigh the change in volume. However, the two girls who asked these questions to start with, guessed that the dry sponge would be denser and seemed bent on proving their hypothesis. Students took turns carefully measuring the dimensions and masses, and then had their measurements verified by their peers. Since the first student started measuring the length using the standard English units, the others continued using the same units. I recorded the results on a data table (Balasubramanian, 2006g) and showed them how I use Google® to change units from the English to the metric system. For example, I typed in the search box, 2 3/8 inches = ? cm and clicked on search, and bingo, Google® immediately returned (2 3/8) inches = 6.0325 centimeters. Students were thrilled to see this and one student immediately asked "Can Google® convert decimals into percents? [*sic*]" This one student was disappointed that it could not. At any rate, after recording their measurements, we converted them to metric units and calculated the density in metric units. Instead of confirming the hypothesis of the majority of our class, the hypothesis of the two girls seemed to be validated from our initial results. We were now close to the end of our class and I asked them what they had learned from this activity.

Students said this experiment showed them:

> that the wet sponge has less density than dry sponge; we learned numbers like g, cm, length, of wet and dry sponge, that the absorption goes in the middle and the adsorption goes around it. I also learned that Google® cannot convert decimals into percents, and also if you squeeze cotton it traps dirt easier; I learned that the skinny little sponge can grow up to the size of the big one and can weigh the same; I learned that the wet sponge has less density; I learned that the wet sponge has less density by measuring the mass, the weight, and the length and the height of the wet and dry sponge. I also learned that there is absorption and adsorption. Absorption is when the particles go to the inside and adsorption when the particles stay on the outside; I learned that when you get a sponge wet, it gets bigger; I learned that the wet sponge is less dense than dry sponge; I learned that Google® will give you answers to equations; I learned that absorption goes to the middle of the sponge and adsorption is on the outside [sic]."

Although school ended and I had to rush to a class at the University, I could not stop thinking about the results of our experiment. I was thinking about these results all night and decided to investigate our findings further the next day with my eighth graders. I told them about what had happened the previous day and repeated the student's question "Which would be denser, the dry or the wet sponge?" I asked them to design an experiment to investigate this and they repeated the activity. This time though, we used the same sponge, first for the dry sponge activity and then for the wet sponge activity, during our investigation. The results this time, in contrast, confirmed our initial hypothesis that the wet sponge was indeed denser. This was a fascinating learning experience for all of us and I thought my students had done almost a semester's worth of science in just one class. When I shared this thought with the eighth graders and asked them to give me an honest rating from 1-10 on my gut statement, based on their three years of middle-school experience, the average class rating was an eight. I repeated this claim after sharing the new findings with my second sixth grade class as well and commended the two girls from the first sixth grade class for leading us into this interesting investigation. The girl, who asked the question "How do you know the sponge become bigger when its wet then its dry? [sic]," spontaneously took ownership for preparing a PowerPoint® slide show and came up with this interesting presentation (Balasubramanian, 2006g). She was one of my English language learners and a student with pupil services, and her outstanding slide show is further testimony to what might be accomplished when technology becomes an aide to motivated students and competent teachers.

Pretest and Post-test Comparisons

The results from the pilot study using a pretest-post-test design with 56 students (one Grade 8 and two Grade 6 classes), taught at a high-needs middle-school north of Denver during the school's "waning days" (Lyman, 2006) in spring 2006, are summarized below. I

Group	N	Pretest Mean (%)	Pretest SD (%)	Post-test Mean (%)	Post-test SD (%)	t-value	p-value	Pre-Post Δ (%)
Entire Class	56	37.9±2.3	17.1	52.4±2.4	18.1	6.230	<.001	14.5±4.7
Caucasian Male	13	50.8±5.0	18.1	57.7±4.0	14.4	1.326	.209	6.9±9.0
Girls	29	34.3±2.6	14.2	50.6±3.8	20.3	5.011	<.001	16.3±6.4
Ethnic Minorities	26	33.8±2.7	14.0	49.6±3.0	15.3	5.448	<.001	15.8±5.7
Pupil Services	21	29.4±2.8	12.7	44.4±3.6	16.6	4.238	<.001	15.0±6.4

Fig. 6. Summary of two-tailed, paired sample t-tests on hydrologic cycle test (before and after direct instruction)

Group	N	Pretest Mean (%)	Pretest SD (%)	Post-test Mean (%)	Post-test SD (%)	t-value	p-value	Pre-Post Δ (%)
Entire Class	56	39.4±1.4	10.6	58.5±2.2	16.6	10.282	<.001	19.1±3.6
Caucasian Male	13	40.7±2.2	8.1	65.4±5.0	17.9	5.656	<.001	24.7±7.2
Girls	29	40.5±2.1	11.2	57.2±2.9	15.6	7.593	<.001	16.7±5.0
Ethnic Minorities	26	38.5±2.0	10.1	53.4±3.0	15.3	5.336	<.001	14.9±5.0
Pupil Services	21	35.1±2.0	9.4	50.3±3.1	14.1	4.975	<.001	15.2±5.1

Fig. 7. Summary of two-tailed, paired sample t-tests on water test (before and after guided-inquiry hands-on activity)

developed the 60 multiple-choice questions from the two-dimensional Bloom's taxonomy (Balasubramanian, 2005b) to assess students' science, technology and pre-engineering knowledge and skills. I used the same 60 questions for both the pretest and post-test.

Interestingly, despite the small sample sizes and minimal teacher intervention, the mean test scores increased significantly (except for direct instruction for Caucasian male students) from pretest to post-test for the entire class, even with disaggregated data by gender, ethnic minorities (African-Americans and Latinos) and pupil services (SPED, ILP, IEP & Math Lab). These gains are statistically significant (at the established 0.05 level and $p < .001$) suggesting less than .1% probability that the observed differences happened by chance. The number after ± in the pretest and post-test mean scores is the error, the standard error of the mean – the standard deviation of the distribution of the mean of samples.

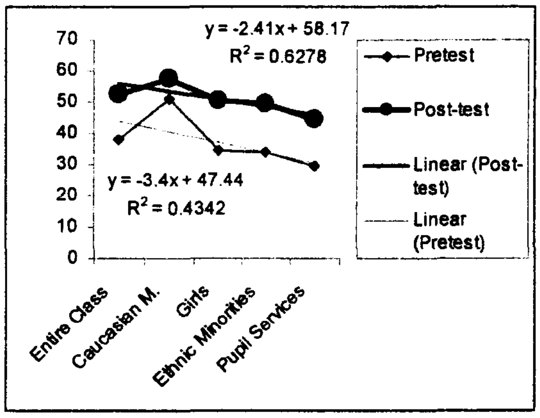


Fig. 8. Pretest and Post-test scores of four subgroups in the 18-item hydrologic cycle test in the filter project, before and after direct instruction

I further examined the pretest and post-test scores of these 56 students and found that the questions were highly correlated. This suggests that the observed changes in students' scores may not be attributed to the regression effect, a regression towards the mean. Instead, all subgroups had actually made significant gains in their post-test scores as Figures 8 and 9 illustrate.

The y-intercept of the trend lines in Figures 8 and 9 for the pretest and post-test data provides interesting information. For the direct instruction, student achievement increased from 47.4% to 58.2%, showing a 10.8% performance gain. However, for the guided-inquiry hands-on activity, the increase in student achievement almost doubled, increasing from 42.1% to 65.5%, showing a 23.4% performance gain.

These numbers are promising when we consider the stark inequities in engineering education in American society. With decreasing trends in engineering in recent years (Douglas et al., 2004), "Female students make up 20% of engineering undergraduates, but 55% of all undergraduates; African-Americans, 5.3% in engineering, 10.8% overall; and Latinos, 5.4%, compared to 6.4% overall" (p. 5). Experts nationally have noticed these trends and consciously try to recruit more minorities in science and engineering through outreach programs. However, the Caucasian male students and their parents, who are not aware of these trends often feel left out when institutions or teachers talk about these equity issues. The findings from this study might comfort them, because they show that with well designed guided-inquiry hands-on science and technology instruction,

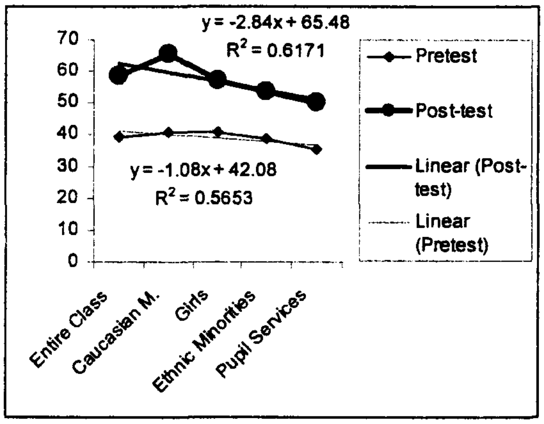


Fig. 9. Pretest and Post-test scores of four subgroups in the 42-item water test in the filter project, before and after guided-inquiry hands-on activity

Caucasian male students also make significant learning gains in the post-test scores, 24.7%, more than the 23.4% gain in the trend line. Evidently, guided-inquiry hands-on learning not only addresses equity issues and increases student achievement for all subgroups of learners but it also results in significant learning gains for the Caucasian male students.

Conclusion

We started this chapter by introducing the challenges and questions that teacher practitioners have to deal with in today's classrooms. While students might come from different backgrounds and differing abilities, learning is enhanced when students are recognized as co-creators of knowledge in the classroom and are able to build on their existing knowledge. In addition to providing content expertise, a teacher's role is more of a facilitator who is responsive to learner needs and actions. We described how the curriculum standards were operationalized by a teacher through design of a guided-inquiry module that resulted in significant learning gains for all subgroups of learners. While substantially hands-on and inquiry-based, the module included elements of direct instruction and game-like activities. Moreover, the narrative in section 4.1 illustrated how inquiry activities lend themselves to unforeseen teachable moments based on students' questions, adding a spontaneous level of true inquiry for teacher and students alike.

Our secondary school students arrive in our classrooms ready to collaborate in both face-to-face and online environments. Teaching and learning are enhanced when teachers use tools like online discussion forums and interactive games and simulations, which can be embedded in course management systems to aid reflection, data collection, and student engagement (Balasubramanian, 2006a; Balasubramanian & Wilson, 2006; Wilson et al., 2006).

In this chapter we presented a conceptual model of teaching and learning as an evolving activity system in which the "higher literacy skills" of critical thinking, mathematical reasoning, inference making, and creative problem solving are nurtured through guided-inquiry hands-on activities. Everyone is a winner when students and teachers accept and exploit the evolving nature of such learning environments. Evidently, using these techniques require innovative teacher-leaders who are willing to contribute their time for planning, reflecting, sharing and collaborating with their peers and students to create engaging technology-mediated learning activities in their classrooms.

Chapter 3

INNOVATIVE METHODS OF TEACHING SCIENCE AND ENGINEERING IN SECONDARY SCHOOLS

Abstract

This article describes the design of an interactive learning environment to increase student achievement in secondary schools by addressing students' preconceptions, and promoting purposeful social collaboration, distributed cognition, and contextual learning. The paper presents the framework that guided our design efforts to immerse all students in a progression of guided-inquiry hands-on activities. Students find compelling reasons to learn by responding to authentic science-based challenges, both in simulations and hands-on activities, based on specific instructional objectives from the national standards.

Keywords: Collaboration, Design-Based Research, Games, Learning, Simulations

Introduction

Schools have numerous responsibilities, including teaching the students observation, thinking, reasoning, communication and problem-solving skills. Science and pre-engineering, properly taught, can help schools fulfill these responsibilities because students can *apply* the knowledge and skills learned in their academic subjects to solve practical problems in their science classes. In particular, developing students conceptual understanding and analytical abilities through *doing* authentic science-based guided inquiry hands-on activities enhances students' self-worth and confidence, and consequently improves their school-wide academic achievement.

Inquiry-based teaching, however, requires highly structured instructional strategies and, as Cozzens (1997) remarks, demands teachers who are knowledgeable about both scientific content and pedagogy. Findings reported by Bransford et al. (2000) and Jensen (1998) about effective teaching and learning strategies highlight the importance of

- using appropriate just-in-time learning stimuli
- engaging students' preconceptions prior to teaching them new concepts
- providing deep foundational knowledge
- helping students make appropriate connections within the context of a conceptual framework
- organizing knowledge in ways that facilitate information retrieval and application
- allowing students more opportunities to define learning goals and monitor their progress in achieving them.

Learning, defined by Simon (Balasubramanian & Muth, 2006) as changes that allow systems to *adapt and improve performance*, is influenced by both motivational and cognitive processes. Like Fischer et al. (2005), we believe intelligence and creativity are generated and sustained through active collaboration, interactions, dialogue, and shared interests between individuals and their socio-technical environments.

However, facilitating the learning and development of students' purposeful social collaborative skills in classrooms during team-based, hands-on problem-solving inquiry-activities presents perennial challenges for several reasons. The lead author, during his 17 years of teaching science and technology in middle and high schools, has found the following challenges to be the most demanding.

• Motivating *all* students
• Increasing the cognitive skills of resource-deprived students
• Sustaining student engagement
• Addressing students' preconceptions
• Creating time to participate and contribute effectively during individual teams' discussions and building activities (with 7 – 10 teams typically in each class)
• Promoting greater social collaboration within and between teams
• Resolving problems with group dynamics
• Coping with students' "Been There, Done That" attitude
• Inducing students to build well thought out designs while advancing their metacognitive skills
• Constantly developing genuinely interesting challenges and activities.

Etheredge and Rudnitsky (2003) observed that fully implementing findings from research and coping with classroom reality has often been overwhelming for teachers and students. This paper describes our *preliminary efforts* at addressing these challenges using a design experiment to inform both theory and practice. The conceptual framework (section 3.1) describes the theory. Concurrently, we developed a prototype and necessary instruction for teaching the concept (NRC, 1996) that "electrical circuits require a complete loop through which an electrical current can pass" (p. 127) to middle-school students.

Structured-Scenario Online Games

Why Structured Scenario Online Games?

The middle-school wonder years are critical periods in the personal, emotional, social, and cognitive development of students. During this period, students have a tendency to rush through building activities without much reflection. Bransford and Donovan (2005) observe that this is due to students' preconception of experimentation as a way of trying things out instead of *testing* their *ideas.*

Balasubramanian and Wilson (2006) describe students' enthusiasm for learning and sharing their experience after playing the promising educational games designed by the Nobel foundation. We define a game as an *engaging interactive learning environment that captivates a player by offering challenges that require increasing levels of mastery.* The Laser Challenge Game (2005) designed by the Nobel Foundation exemplifies this definition. In our classroom study, we found that all middle-school students, disaggregated by gender and ethnicity, made significant learning gains after playing the challenging Nobel games.

Believing in our five guidelines (2006) that are necessary for games and simulations to be meaningfully integrated into classrooms, we designed STRuctured-scenario ONline Games (STRONG, in short) as modular, self-contained, easily accessible, multi-player, online *interactive learning environments*, to direct, facilitate, and assess students' conceptual science, technology, engineering, and mathematics (STEM) understanding through deliberate reflection.

STRONG scenarios and challenges are designed to promote a deliberate *STOP → REFLECT → THINK → ACT* approach to rekindle students' intentionality and inherent preference for goal-oriented actions. Besides, as Balasubramanian (2003) discussed, such deliberate thinking fosters self-organized learning. Schön (1983) remarked that such "reflection-in-action" situations also foster new ways of thinking and coping with surprises. The engaging scenarios in STRONG unfold as cliff-hanger chains of events to captivate students' attention, stimulate their motivation, and provide meaningful contexts for learning. For instance, a dialogue between Peggy and Cassandra (fictitious names for students' online avatars, Fig. 1) in our STRONG prototype under development, sets the tone for students finding compelling reasons to design a warning device after they have suddenly fallen into a dark cave during a hiking adventure.

Peggy: Oh great! Now what are we going to do?
Cassandra: Sweet! Let's play cops and robbers.
Peggy: We need to get help quick.
Cassandra: Are you kidding me? This is freaking awesome.
Peggy: Are you kidding ME? This is freaking . . . FREAKY.
Cassandra: No way, this is the ultimate opportunity to play the best, the most extreme, the greatest game of cops and robbers known to humankind.
Peggy: OK, just one game, but after that we're getting help.
Cassandra: Deal! I'm the robber, you try to find me.
Peggy: OK, go. (a couple of minutes pass)
Peggy: Uh Oh! I can't find you. This is scary. Where are - - (cut off because she fell). I tripped on a rock. Help me.
Cassandra: HA HA HA, you tripped. I mean . . . are you okay?
Peggy: Yes, I'm fine. I tripped on this rock.
Cassandra: That's not a rock. It's a treasure chest from the old Captain Willy.
Peggy: I don't think we should open it, there could be something dangerous in there. Let's get help first.
Cassandra: Oh yeah! I have my cell phone, we could just call my mom.
Peggy: Why didn't you think of this before?
Cassandra: Uh oh . . .
Peggy: What?
Cassandra: No signal, I hate my phone service, it never works
Peggy: We're doomed. Well, I guess we could open the box to see what's in it . . .
Cassandra: It's not a box. It's a treasure, but let's look inside. (open the box)

Peggy: It's some wire and . . .
Cassandra: Gold?
Peggy: No a light bulb and . . .
Cassandra: Gold?
Peggy: No a battery. We can put this together to make a signal to get us out of this eerie place.
Cassandra: We could scream for help, someone might hear us as well.

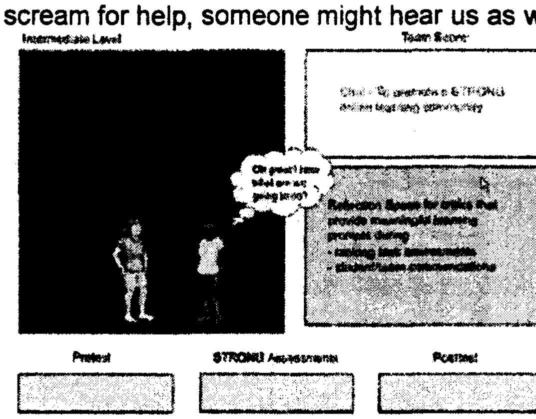


Fig. 1 The STRONG Interface

Then a circuit construction (PhET, 2005) Java simulation pops up on the screen for students to experiment with and build circuits for a warning device using wires, three light bulbs, two batteries, and switches in a safe and non-threatening environment. When students use two batteries, they learn that there is a right way and a wrong way to connect batteries. Using three light bulbs leads to a better understanding of series and parallel circuits.

STRONG scenarios are designed to enable more students to view surprise and failure as potential opportunities that help them develop good problem-solving, reasoning, and critical thinking skills as outlined in the *Benchmarks for Science Literacy* (AAAS, 1993).

Curriculum-centered design

From their review of educational gaming literature over a period of 28 years, Randel et al. (1992) concluded that games could be used effectively to provoke interest, teach domain knowledge, and shore up retention in math, physics, and language arts when *specific* instructional objectives were targeted.

In our early design of STRONG, students learn, use and understand *one* concept from the *National Science Education Standards* (NRC, 1996), "electrical circuits require a complete loop through which an electrical current can pass" (p. 127), while building simple electrical circuits for a warning device. Along with this concept, players of STRONG will learn and use the knowledge and skills in three labeled strands in the *Atlas for Science Literacy* (AAAS, 2001): lines of reasoning, failure, and interacting parts.

There are four levels in STRONG: beginner, intermediate, proficient, and advanced to correspond with the primary, (K-2), elementary, (3-5), middle, (5-8), and high, (9-12) school grades in the *Benchmarks* (1993). The outcome variables in these four levels of STRONG are the developmentally appropriate STEM knowledge and skills tabulated and color-coded at http://www.GamesToLearn.us/ConceptForSTRONGPrototype.htm. Using appropriate scenarios, these *Benchmarks* (1993) are packaged as appropriate challenges for students in the different levels of the game, to interest both resource-deprived and resource-affluent students in their preparation for active inquiry learning.

For instance, at the intermediate level of the game, players demonstrate understanding of how a simple circuit is connected by wiring a warning device using only one light bulb, one battery, and one wire and answering assessment questions correctly. The corresponding *Benchmark* (1993) on failure, 11A/E2, requires students to know that "something may not work as well (or at all) if a part of it is missing, broken, worn out, or misconnected" (p. 264).

Conceptual Framework

The STRONG Plus Model

Hands-on inquiry learning without domain knowledge merely entertains students and results in their inadequate conceptual understanding. Many resource-deprived students reach schools with limited cognitive skills and are consequently less motivated. Wilson (1997) observed that direct instruction to impart domain knowledge in sterile learning environments left students unenlightened and unable to see its real-world relevance. To cope with this dilemma, we describe the STRONG Plus framework that seeks to immerse all

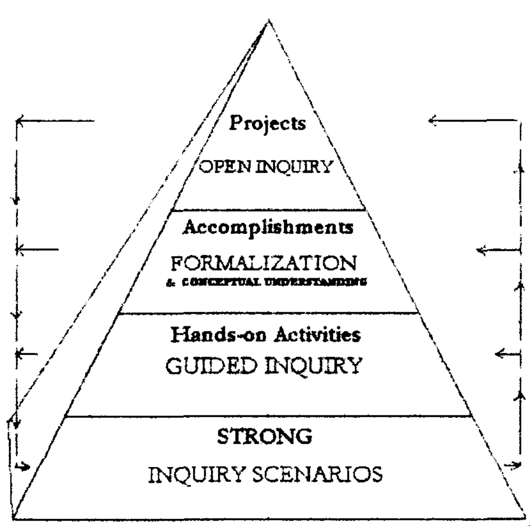


Fig. 2 The STRONG Plus Model, illustrating our conceptual framework.

students in a progression of guided inquiry hands-on activities to facilitate their conceptual STEM understanding, starting with STRONG and proceeding to less guided forms of inquiry learning (see Fig. 2).

The pedagogical strategy underlying this conceptual framework is adapted from Vygotsky's model of developmental teaching. Giest and Lompscher (2003) propose three stages in Vygotsky's zones of student development: *learn-by-doing* in students' zone of actual performance (ZAP), *learn-by-inquiry* in their zone of proximal development (ZPD), and *learn-by-developmental teaching* where they construct and develop their understanding when their ZPD becomes their new ZAP and so on.

Although designed to be pre-reflective of the formal subject matter, STRONG elicits, first of all, students' rudimentary and incomplete conceptual understanding and prior knowledge in their ZAP. Students work in teams (of two recommended) to solve challenging problems and accomplish various goals embedded in the game. The small-team setting promotes greater sharing of ideas among young adolescents without fear of negative judgment by their peers, and helps elicit their preconceptions and fragile conceptual understanding during their social interactions and peer mentoring.

McDonald and Hannafin (2003) noted that web-based games promote higher order learning outcomes and understanding because they increase meaningful dialogue among the students and help identify students' misconceptions, both of which are not easily obtained in traditional classrooms without conscious teacher mediation. Bransford and Donovan (2005) refer to the success of a computer-based DIAGNOSER in increasing students' understanding of high school physics concepts when the program helped teachers elicit students' preconceptions.

Although rudimentary, the STEM content- and context-specific student discussions necessitated through play in STRONG, empowers students with new ways to talk, think, and act in middle schools (Roth, 2002).

After engaging all students using the game, teachers could use the student performance data to provide formal explanations, promote further reflection, and guided-inquiry hands-on activities to develop students' knowledge and formal conceptual understanding in their ZPD, before formally assessing student accomplishments.

According to Perkins (1998), students' flexibility in thinking and performing hands-on activities, beyond the rote and the routine, is one measure of their understanding. Then, observing students' creative and imaginative solutions to problems, and finally students' attitude and engagement towards challenges encountered during hands-on activities are other authentic metrics of understanding.

Finally, students learn through developmental teaching using projects and problem solving. In developmental teaching, students' ZPD in the second stage becomes a new ZAP. This *iterative* process continues through the three stages as students transition to higher levels of learning and become more active self-directed learners.

The STRONG Plus model in Fig. 2 illustrates our preference for engaging all students with the game first, then providing them with formal explanations and opportunities for hands-on investigations, and concluding with formal assessments and projects to promote conceptual STEM understanding.

Collaborative Problem Solving and Reflection

Collaborative problem solving and deliberate reflection are two cornerstones in all four stages of the STRONG Plus model. Starting with a well-designed game increases the domain knowledge and motivation of all students because more students would have an opportunity to participate in stimulating and thoughtful conversations in a non-threatening high-challenge small-group gaming environment, before engaging in less guided forms of hands-on inquiry learning.

Reports from classroom observations, like the one from Horizon Research (Weiss et al., 2003), show that the weakest elements observed in science and mathematics classrooms are the limited time, opportunity, and structure for students to engage, ask questions, and understand all the material. Tools, like STRONG, provide a basis for more doing, testing, reflection and metacognition among middle-school students. Bransford and Donovan (2005) describe how using *ThinkerTools*, a physics inquiry curriculum, the low-achieving students from inner-city schools have shown a deeper conceptual understanding of physics because of the metacognitive component in the reflective assessments.

STRONG requires little or no teacher intervention during play. However, students' typed responses in the assessment fields are recorded and processed continuously during the 15-20 minutes of play. Students receive instant feedback on their performance, in the assessment windows and reflection space, from embedded critics in the game.

Critics are agents that provide context-specific advice to users based on their inputs in a computational environment. As observed by Cios et al. (1998), the dynamic feedback students receive, based on the embedded fuzzy logic and machine learning techniques in the STRONG system architecture, promote students' active learning.

Prototype of Strong

Design-Based Research

Section one in this paper discussed the complexities and challenges associated with STEM teaching and learning. Section two described how STRONG uses backward design (Wiggins & McTighe, 1998), an outcomes-oriented approach requiring identification of desired learning goals and then working backwards to develop meaningful learning opportunities and assessments, to promote learning. The STRONG Plus model elaborated on in section three described how the dilemma of "informing" through direct instruction and "doing" in inquiry-based learning might be reconciled.

We considered the development of our prototype as a design experiment because it afforded us opportunities to theorize and address the complexities associated with learning. Cobb et al. (2003) recommend that the primary goal of facilitating learning is to improve initial designs by repeatedly testing and revising conjectures. These recommendations have guided us in the development of the STRONG Plus framework and we subsequently used this theoretical model to design a prototype that facilitates student learning.

In addition to teacher observations and feedback, tools like STRONG will help researchers gather real-time data on student learning and performance. Besides, student performance on their diagnostic assessments (their online pre-tests) and post-tests are used to test and improve the design of our prototype.

In summary, our research agenda has a two-fold purpose. The STRONG Plus model depicts our early efforts at developing a theory. Designing a prototype as we developed assessments and necessary instructional support materials to improve practice is another.

Contextual and Experiential Learning

The case study by Yeo et al. (2004) and our personal experiences show that interactivity and animated graphics in games and simulations, by themselves, do not help students learn basic scientific and engineering concepts. Students need additional supports to promote deep conceptual understanding. The Flash animated scenarios in the game not only provide a context and purpose but they also motivate students by enabling them to *do* science.

When students are ready to test their understanding of a concept, say, "electrical circuits require a complete loop through which an electrical current can pass," they will answer six questions that promote their higher order thinking. These six questions are generated randomly from a library of twenty-five questions, unique to each level of the game. This will minimize chances of students misusing the online chat to exchange notes with correct answers.

For instance, in one type of question having *several* possible correct answers, a student will have to select all choices that apply. The possible answers might include: The wire is warm cold; the light bulb is on off; the light bulb glows very bright and burns out does not burn out.

Students' correct, partially correct, and wrong answers have pre-assigned fuzzy logic scores from +1 to -1. This is combined with another unique feature in STRONG asking students "How confident are you in your answer?" The *confidence multiplier*, varying from 1 – 10, for "I am guessing" and "I am 100% confident," respectively, multiplies the raw score (with fuzzy values between -1 and +1), before displaying scaled team scores.

With numerous genres available, the term "game" has been elusive to define. Glazier (1973), Prensky (2001), and Rasmusen (2001), have described the presence of the following basic components in games: 1) Player Roles, 2) Game Rules, 3) Goals and Objectives, 4) Puzzles or Problems (Challenges), 5) Narrative or Story, 6) Players' Interactions, 7) Payoffs and Strategies, and 8) Outcomes and Feedback. Our games, defined as *engaging interactive learning environments that captivate a player by offering challenges that require increasing levels of mastery*, include these basic components (Table 1).

Table 1: STRONG and Basic Components in our Rudimentary Game – Intermediate Level

Basic Game Components	STRONG
1. Player Roles	Players select one of the six online avatars and watch scenarios unfold. Our current design does not give players more freedom and control over their clothes and their environment, but these power-ups will be incorporated in subsequent designs to reward higher team scores.
2. Game Rules	Students take a pretest (hands-on and online), watch engaging scenarios unfold as Flash movies, use embedded electrical circuit construction Java simulations, answer six randomly selected questions, and take a post test (hands-on and online).
3. Goals and Objectives	Players will learn, use and understand at least *one* core concept from the standards, while building simple electrical circuits for a warning device.
4. Puzzles or Problems (Challenges)	Players demonstrate an understanding of how a simple circuit might be connected for wiring a warning device, using only one light bulb and a battery. Each STRONG assessment question is a puzzle or problem or challenge in itself.
5. Narrative or Story	The dialogue about cops and robbers between Peggy and Cassandra when their cave is suddenly engulfed in darkness depicts a typical scenario in STRONG.
6. Players' Interactions	Student discussions, building various circuit designs using hands-on and Java simulations, answering six questions

	(three for each player) for assessment even as they alternate and collaborate represents expected interactions.
7. Payoffs and Strategies	What kind of confidence multiplier factors might players use? With raw scores varying from -1 to +1, multiplying it with a multiplier could change the final scaled team scores significantly.
8. Outcomes and Feedback (Embodying concepts to be learned	Players learn and demonstrate understanding of the concept "electrical circuits require a complete loop through which an electrical current can pass," after reflection on the critiques and feedback in the STRONG prototype.

As students play the game, real-time data on their performance will be collected into a database. The embedded critics in the game will offer contextual clues, when necessary. For example, a comment in the reflection space could be "Have you considered connecting this circuit in the Java simulation and seeing what happens?" The contents on the STRONG home page http://GamesToLearn.us include relevant *Benchmarks* (1993), sample worked examples, STRONG assessment, and links to the Java simulations of a STRONG prototype.

Next Steps

Mitchell and Savill-Smith (2004) noted that players' limited pre-existing computer skills, teacher bias towards learning methods, and possible conflict between game and learning objectives could impact the benefits of using a game, but as knowledge engineers of STRONG, we believe the effect of these would be minimal because of the game design.

The STRONG Plus model has guided our design efforts in developing a prototype to help students explore and understand electrical circuits. While the existing prototype can be played online at http://GamesToLearn.us, we continue testing and improving our initial design.

In conclusion, a tool like STRONG empowers both students and teachers. STRONG meets learner needs because it supports students' preference for *learning by doing*. STRONG is promising for instructors because it supports teachers who engage students with hands-on inquiry learning. A solid foundation in STEM during students' critical developmental years will help them enhance their lifelong learning goals.

Chapter 4

INCREASING STUDENT ACHIEVEMENT THROUGH MEANINGFUL, AUTHENTIC ASSESSMENT

Abstract

This paper describes how the author uses an online communication and assessment tool, *SchoolFusion*, to (a) monitor and manage middle-school students' work and provide them immediate feedback, (b) collect real-time data on students' understanding of science and engineering concepts, and (c) use the information gathered to guide subsequent instruction. Quantitative data analysis showed that the mean test scores increased significantly from the pre-test to the post-test across the entire class. Students' responses in online think-writes also revealed students' improved conceptual understanding of scientific and engineering principles.

Introduction

It was Friday evening, four weeks after school reopened. I noticed my colleague at Angevine Middle School walking out of school carrying a "case" overflowing with over eight reams of students' mathematics worksheets for grading over the weekend. Not long ago I too had carried reams of physics papers for grading over weekends, not always completing my planned marking. As teachers we are often overwhelmed with a backlog of papers to grade and continue with our daily instruction, regardless. Meanwhile, students miss the timely feedback that impacts their learning. Obtaining and using data on students' individual learning in the classroom on a daily basis is a challenge.

On top of all this, with increased calls for accountability in school systems and fear of federal sanctions based on the *No Child Left Behind* (NCLB) Act of 2001, several schools have had to shuffle priorities and focus on reading and mathematics, while other subjects have been relegated to lesser importance. In Colorado, students are "tested" in science only at the end of Grade 8, and soon will be in Grade 5. However, there will be no data on their yearly performance. Not surprisingly, the authors in the *Designs for Science Literacy* (AAAS, 2001) observed that "students learn too little in science" (p. 51) because there is not enough time for teaching and learning science.

Besides, going by reports from the *Program for International Student Assessment* (PISA) http://www.pisa.oecd.org and the third version of the trends in *Trends in International Mathematics and Science Study* http://nces.ed.gov/timss/ (TIMSS) studies, there is growing concern and debate about students' problem-solving abilities. Inspired by Russell's (2004) article in a special issue of *Curriculum Inquiry*, my comments in *Education Week* (Balasubramanian, 2004) highlighted related questions: How do we select the most appropriate materials to teach? How do we determine the most efficient and effective ways to teach this material? Are we teaching as well as we can? Are we teaching as many students as we can? Do the techniques employed in schools enhance students' self-worth and confidence? Do we have ways of using and monitoring ongoing formative assessment?

In this paper, I illustrate how teachers can motivate and empower *all* students through positive and timely feedback by using an online learning management system effectively.

Learning Management System (LMS)

Besides weblogs and wiki-variations, commercial and open source Internet-based learning management systems – marketed as content management systems or course management systems – are burgeoning. These website-in-a-box technologies are often perceived and presented as the panacea for K-16 and lifelong education. Ellen Rose (2004), peppered with Cassandra-like prognostications, raises valid questions about the ideologies and assumptions underlying the emergent website-in-a-box technologies in her paper. She traces the origins of these purportedly "personalized, meaningful, empowering, and ultimately learner-centered educational environments" (p. 57) to the low-tech teaching machines of the 1950s, computer-assisted instruction (CAI) of the 1980s, and integrated learning systems of the 1990s that promised individualized instruction.

Ellen Rose argues that these emergent technologies are really Trojan horses that seek to replace human interactions in the classroom. They are neither teacher-centered not learner-centered but merely technology-centered systems, she alleges. Although computer managed instruction (CMI) might appear to be a teacher's tireless machine servant to record students' progress, "pre- and post-test scores, and the like" (p. 52), they are driven by the vested interests of CMI researchers, Ellen asserts. According to her, the emerging online website-in-a-box technologies promote a cult of efficiency, atomized content delivery, and static classroom packages while demanding that teachers relinquish their decision-making powers to these technologies.

In this paper, I illustrate how I use one of these commercial content management systems effectively in my classroom to monitor, manage, and use data to inform my classroom instruction – more like a CMI without the vested interests of a CMI researcher. Although I gathered information on students' aptitudes and attitudes in past years, I had not done any formal study on their learning. Since I had access to a new, free LMS that I use as an online communication and assessment tool, I felt confident that I could pursue a more systematic exploratory study using pre- and post-tests.

I was keen on finding out what, if any, students were learning in my classes. I wondered whether I would see an improvement in student scores after instruction. Specifically, would I see improvements that were independent of gender and ethnicity? The following sections illustrate how I designed my courses around four critical organizational questions that guide teaching and learning: learning, instruction, assessment, and alignment questions, following Anderson and Krathwohl (2001, p. 6).

The Learning Question

Students spend just 14% of their time in school each year (Bransford et al., 2000). *What is important for students to learn in the limited school and classroom time available?*

Following a training in Fall 2002, teachers at Angevine are expected to have learning objectives written on the board, following the SIOP Model (Echevarria, et al., 2000). During one of her classroom observations in October 2003, the Principal of Angevine remarked: "Try and focus on what the outcome of the learning is, rather than on the task." My learning objectives have since, gradually, become specific.

Students in the applied technology classes were learning various scientific and engineering principles through building activities. For instance, in Designing Beams, I had specific expectations on students' learning objectives and vocabulary, in contrast to Heavner et al., (2004) "Breaking Beams." My objectives were students will: (a) recognize various types of beam designs; (b) understand forces, especially forces of tension and compression; (c) explain, where in the beam, these forces are greatest and why; (d) rank building costs, depending on materials used, particularly for wood, concrete, reinforced concrete, and steel; (e) design a prototype of a beam using the design process; and (f) test, calculate, explain and evaluate the strength-to-mass ratio of their beams.

The Instruction Question

How does one plan and deliver instruction that will result in high levels of learning for large numbers of students?

Since Fall 2004, students at Angevine also take Cornell notes during classroom instruction. Teachers have encouraged and modeled quality note-taking in all classes, and this section describes how students tracked their progress in their technology classes.

Students' learning, their ability to *adapt and improve performance*, is influenced by both motivational and cognitive processes (Balasubramanian, Wilson, & Cios, 2005). I digress briefly to mention that in all my classes, students work in teams on numerous hands-on and minds-on activities by *doing* and *applying* concepts learned at school. Hands-on, in practice, translates to resource-intensive and more planning. Furthermore, early in Fall 2004, I learned how Monopoly-like money can be a significant motivator for learning in middle schools. My description of a creative activity (Balasubramanian, 2005d), provides a brief description of this serendipitous discovery. This "microeconomy" through monetary monitoring has evolved into a full-fledged classroom management system (Balasubramanian, 2005c) and is part of another paper describing ongoing assessment of students' learning.

Before students received any instruction on designing beams, they took a timed online pre-test. Such tests are easy to create using the flexible online K-12 learning management system developed by the www.SchoolFusion.com team. I could experiment with the tool for free because the developers offer their classroom course shells, free for life, for the "first three teachers in any school in United States." My classes can be viewed at www.angevine.groupfusion.net

Students then received a half-hour instruction that addressed the six learning objectives outlined earlier. With money being a significant motivator, students actively participated throughout the class discussions. The tools students use in class are always free, but each team then bought their supplies. One yard of balsa wood cost $200 and a bottle of wood glue cost $50. After brainstorming and sketching their designs on graph paper in ten minutes, teams had another half-hour to build their design. They used clamps to secure their designs and let them dry over the weekend.

The Assessment Question

> *How does one select or design assessment instruments and procedures that provide accurate information about how well students are learning?* More importantly, how does one use this information to inform instruction?

At Angevine, since Fall 2004, teachers are required to have students track their academic progress through Assignment Logs, containing a record of all their graded work. Students had well over ten graded assignments in their logs in just four weeks because they did their quizzes and think-writes on their class website.

In *Systems for State Science Assessment*, Wilson and Bertenthal (2005) summarize 18 assessment approaches to cope with impending NCLB mandates. The *written pre-test*, *drawing* and students' *problem-solving* abilities in designing beams described so far illustrate three strategies that assess students' understanding.

During their next class, students tested their beams (Movie # 12 in Balasubramanian, 2005e). The oral *presentations* afford opportunities to assess students' communication skills. I use these presentations for *peer-assessments* too. After every presentation, the captains of each team confer with team members and write down scores based on a 50-point scoring rubric using five criteria: *design*, *creativity*, *explanation*, *cost efficiency*, and *test-endurance*.

Following their presentations, I wrote down the test results on a transparency and we discussed them as a class. The results of the ten teams are summarized in Fig. 1. The first five were from the first class and the last five are from the second class. Interestingly, in both classes, the beams that won (Team 3 and Team 10) did not withstand the most load. Consequently, students understood the importance of "strength-to-mass" ratio. In the second class, with the results being so close, Team 6 was disappointed at not winning because their beam withstood the greatest load of 229 g. Consequently, they had questions about Team 10's weighing. The two teams verified each other's weighing using a triple beam balance and, reluctantly, Team 6 declared Team 10 the winners.

Team No	Mass of beam (in g.)	Load on beam (in lbs.)	Strength-to-mass ratio (in lbs/g)
1	23.0	358	15.6
2	16.0	185	11.6
3	14.0	254	18.1
4	22.8	41	1.8
5	14.5	44	3.0
6	19.0	229	12.1
7	10.0	29	2.9
8	17.6	174	9.9
9	20.5	213	10.4
10	12.7	161	12.7

Fig. 1. Strength-to-mass ratio of different teams

To follow up on their written assessment, students took an online post-test titled "Beams, Materials, and Forces." Although the questions in the two tests were the same, the order of questions was different and the tests had different "titles." Almost all the students thought they were taking different tests. This is another advantage of using *SchoolFusion*. As teachers, we can create these tests, besides mid-term or end-of-term tests, easily using the Online Quiz feature from a repository of questions we have created throughout the semester. Moreover, I found it was easier to cope with common classroom challenges associated with students' tardiness, truancy, absence, and desire to improve their grades with make-up tests. The instructions, tests, and students' responses are all online and easy to monitor.

I have embraced this pre- and post-test approach for all my classes since Fall 2005. In the following paragraph, I report results from my Applied Technology classes because I could perform meaningful statistically analyses. In the other classes, with less that 30 students, I have noticed similar trends on improvement in students' performance but they were smaller sample sizes.

I printed the pre-test and post-test scores from *SchoolFusion* and analyzed them using the *Statistical Package for the Social Sciences* (SPSS). The results are summarized in Fig. 2 below.

Group	N	Pretest Mean (%)	Pretest SD (%)	Post-test Mean (%)	Post-test SD (%)	t-value	df	p- value
Entire Class	34	45.0	23.4	68.9	20.9	4.553	33	< .0001
Caucasian M.	18	47.7	24.3	69.1	21.5	3.621	17	.002
Minorities	16	42.0	22.7	68.8	21.0	3.928	15	.01

Fig. 2. Summary of two-tailed, paired sample t-tests for beams, materials, and forces

Even for such small sample sizes, the two-tailed, paired sample, t-tests show that the mean test *scores increased significantly* from the pre-test to the post-test, irrespective of gender and ethnicity, *across the entire class*. Even with disaggregated data, by ethnicity and minority students (Girls, Hispanics, African Americans, and American Indians), the *mean test scores increased significantly for the two groups*. Clearly, this study cannot be construed as a valid scientifically based research because there was no control group (Slavin, 2003). However, p = .01 means that there is 1% probability that the observed difference among minority students happened by chance.

To complete the Designing Beams activity, students reflected on their learning and completed a confidential *self-assessment* using another grading inventory and rubric. They also reported on team members' individual contributions during the design activity and assigned percentages. Using money, it was easy for them to express percentages, because they were asked "How would you divide $100 between the members of your team based on each individual's contributions?" I was pleasantly surprised by one team in particular. The individual and the other two in the team reported 45%, 45%, and 10%. Although I was moving between the five teams, I had not noticed that this one student was doing little work.

Although contentious, recently Jonassen (2005) argued that "the only legitimate goal of education is problem solving." Students repeatedly hear that the most important concept they will learn in my class throughout the semester is creative problem solving using a systems approach. Students receive a blank grading inventory and rubric at the end of each activity. A sample grading inventory and rubric, illustrating exemplary student responses is available at http://www.innathansworld.com/technology/SampleGradingRubricInventoryNGradingScale.htm The grading inventory reinforces the problem-solving process by requiring students to reflect on their learning while completing their self-assessment.

So far, I described briefly how students' learning might be assessed through multiple measures using written tests, drawing, problem-solving, presentations, peer-assessments, and self-assessments. The following section illustrates how students' work might be assessed though observations, questioning, research products, practical investigations, creative writing, and bundling activities, using examples from a Grade 8 science class.

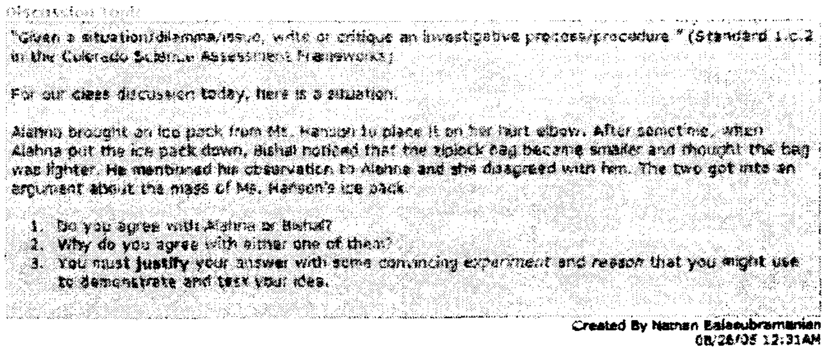
The Alignment Question

How does one ensure that objectives, instruction, and assessment are consistent with one another?

The previous sections illustrated how an outcomes-oriented approach of identifying desired learning goals and then working backwards to develop meaningful learning opportunities and assessments could be used to promote meaningful learning. This backwards design approach (Wiggins and McTighe, 1998) is one way to align assessment with the curriculum.

With high-stakes testing, the slogan "what gets taught is what is tested" is common. Learners do not readily access numerous available online resources (like online discussions and website references). Reeves (2002) observed that often, the learners do not see a relationship between assessment and online resources because they are focused instead on other activities that might help them obtain the highest scores in traditional course assessments.

In my classes, students pay attention to classwork because it counts toward 50% of their grade. The quizzes are 30% and homework is 20%. The homework uses *questioning* and *creative writing* assessment approaches using standards-based online discussions. For example, the Grade 8 science students had to provide thoughtful online responses to the scenario illustrated in Fig. 3. This example illustrates how teachers can use information gathered through essential questions to plan, inform, and modify instruction using feedback from authentic assessments. *Authentic assessments* must be contextualized, be public, require collaboration with others, enable students to show off what they can do, and replicate the actual challenges that typically face a person in the field: conduct original research, analyze the research of others, argue critically, and synthesize divergent viewpoints (Wiggins, 1989).



"Given a situation/dilemma/issue, write or critique an investigative process/procedure." (Standard 1.c.2 in the Colorado Science Assessment Frameworks)

For our class discussion today, here is a situation.

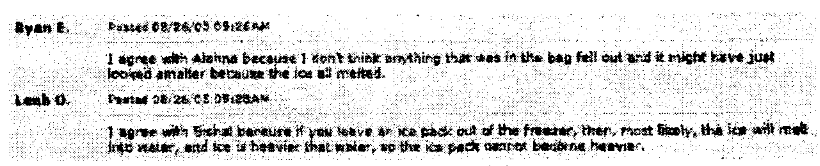
Alahna brought an ice pack from Ms. Hanson to place it on her hurt elbow. After sometime, when Alahna put the ice pack down, Bishal noticed that the ziplock bag became smaller and thought the bag was lighter. He mentioned his observation to Alahna and she disagreed with him. The two got into an argument about the mass of Ms. Hanson's ice pack.

1. Do you agree with Alahna or Bishal?
2. Why do you agree with either one of them?
3. You must **justify** your answer with some convincing *experiment* and *reason* that you might use to demonstrate and test your idea.

Created By Nathan Balasubramanian
08/26/05 12:31AM

Fig. 3. Sample standards-based online discussion

Our school nurse typically made over 85 ice-packs everyday. Students use these ice-packs often and could engage with the dilemma presented. They had to demonstrate their understanding of the concepts of density, melting, evaporation, condensation, and closed systems through their thoughtful responses. Students' individual responses are available in their class website at www.angevine.groupfusion.net Here I illustrate how their thinking evolved over time using two sample student responses. Ryan and Leah's initial responses are illustrated in Fig. 4.



Ryan E. Posted 08/26/05 09:26AM

I agree with Alahna because I don't think anything that was in the bag fell out and it might have just looked smaller because the ice all melted.

Leah O. Posted 08/26/05 09:28AM

I agree with Bishal because if you leave an ice pack out of the freezer, then, most likely, the ice will melt into water, and ice is heavier that water, so the ice pack cannot become heavier.

Fig. 4. Sample students' initial responses

After reading their responses, I asked them to divide themselves into three groups based on their beliefs about the ice-pack becoming lighter, staying the same, or heavier in their second class. There were six, nine, and two students in the three groups, respectively. They had to plan their experiments, and record their discussions and observations on Cornell notes. I used these as the prompts for the following class. They discussed the prompts in pairs and subsequently posted their replies (Fig. 5).

Ryan E. Posted 09/06/05 10:10AM

Ryan's reply:

I thought that this was true because none of the water was leaving the bag, and it couldn't get lighter. (BS) I WAS RIGHT. I think Group A cheated or they had a faulty scale. and their measurement was different from ours.

Feng's reply:

I think that group A is cheating and I agree with Ryan's conclusion.

Leah O. Posted 09/06/05 10:10AM

Anna
I think that the groups got different answers because the groups could of weighed the bags wrong. there could of been more ice in 1 bag then the other

Fig. 5. Sample students' response in their third class.

Following this, we discussed the relevant concepts as a class and students then had to post their final responses using the necessary vocabulary (Fig. 6).

By engaging constructively with the multiple perspectives, students could "confront stereotypes and simplifications about the subject matter" (Gardner, 1991, p. 244) and demonstrate significant learning and development of their analytical and critical thinking skills.

Leah O. Posted 09/08/05 09:53AM

{lEaH}
All of the measurements should've been the same, but group A's became lighter, group B's stayed the same, and group C's became heavier.
I think that group A's could've become lighter because some water in one of the bags could've evaporated faster than in the other bag.
Group B's could've stayed the same because their bag didn't evaporate like group A's did.
Group C's could've gotten heavier because the bag could've been buoyant or filled with condensation.

Ryan E. Posted 09/14/05 08:44AM

I think group A got a lighter measurement because the bag might have been open and some of the water evaporated or spilled out.

I think that group B (our group) measured the water first before any could get out.

I think that Group C had a heavier measurement because condencation caused moisture to gather on the outside of the bag.

Fig. 6. Sample students' response in their fourth class

In conclusion: This paper described how students and teachers receive timely feedback on students' performance in pre-tests and think-writes before engaging in formal classroom learning. Although extremely powerful for formative evaluation and informing instruction, the online learning management system does not support graphics during test design. Besides, this exploratory study was not scientifically based because there was no control group. Nevertheless, it demonstrates how *all* students assumed responsibility for learning and I had evidence of individual students' improved conceptual understanding.

Chapter 5

GAMES AND SIMULATIONS

Abstract

This overview examines the challenges and opportunities afforded by games and simulations to enrich teaching and learning. It presents the preliminary findings from a classroom study that used the promising educational games and simulations developed by the Nobel Foundation. Middle school students from all groups, disaggregated by gender and ethnicity, showed significant learning gains after playing these challenging Nobel games. We recommend five guidelines that are necessary for games and simulations to be meaningfully integrated into classrooms.

Introduction

Improving schools internationally is the greatest challenge of our generation – Clark Aldrich (2004, p. 229)

Early studies show that gamers perceive the world more clearly, are more creative problem solvers, are more confident, and are more social – Steven Johnson (2005)

We juxtaposed these two divergent comments because games and simulations offer tremendous promise to help us cope with the current challenges in education and training. The current technology-savvy generation of students are cognitively more sophisticated and want learning to be fun, engaging, hands-on, challenging, interactive, empowering, and thought provoking. However, some educators continue to think of knowledge and learning in terms of textbooks – sequential, fact-based, and immutable. Students' varied interests and habits of inquiry conflict with traditional textbook-centered classroom instruction, and often result in discipline issues in the classroom.

Simultaneously, the problems facing the world and the workplace are becoming more and more complex. Employers wonder if their employees can be better prepared at schools and universities to cope with today's unique challenges, both nationally and globally. Could simulations and gaming environments stimulate competence, creativity and problem-solving through active collaboration, interactions, dialogue, and shared interests between individuals?

The purpose of this introduction is to examine the challenges and opportunities afforded by games and simulations to enrich teaching and learning. In the latter half of the paper, we assume Nathan's voice as he provides a practitioner's perspective on classroom realities. We conclude with five guidelines that we believe are essential for educational games and simulations to be integrated into classrooms.

Why Games and Simulations?

History and Definitions

Although the idea of using computer games to facilitate learning is being resuscitated with new technologies and fresh thinking, a visit to the library at a local university revealed a shelf-load of textbooks from the late 1950s until early 1970s, centered on using games and simulations in classrooms to facilitate learning. Klietsch's (1969) curriculum guidelines elaborate on the underlying *behavioral-learning systems theory* behind games and simulations. Klietsch details various unique characteristics of behavior-based simulations and games (Unit A, pp. 4-5), which include: goals, capabilities, resources, means, interactions, strategy, engagement, decision-making, and problem-solving requirements. The commercial gaming industry has capitalized on these characteristics and continues to design games that satiate gamers' interests world-wide. The latest snapshot study by the BBC Audience Research (BBC News, 2005) in the UK reported that 59% of the 26.5 million individuals surveyed in the age groups 6 – 65 are gamers – 48% of them women. They concluded that gaming is enjoyed by both genders across all ages in all walks of life.

With numerous genres available, the word "game" has been elusive to define and holds various denotations and connotations. Glazier (1973), Prensky (2001), and Rasmusen (2001) have described the presence of the following basic components in games: 1) Player Roles, 2) Game Rules, 3) Goals and Objectives, 4) Puzzles or Problems (Challenges), 5) Narrative or Story, 6) Players' Interactions, 7) Payoffs and Strategies, and 8) Feedback and Outcomes. We define a game as *an engaging interactive learning environment that captivates a player by offering challenges that require increasing levels of mastery*. The *Laser Challenge Game* (http://nobelprize.org/physics/educational/laser/challenge.html) designed by the Nobel Foundation exemplifies this definition.

Similarly, with wraparounds or scaffolds to advance learning outcomes, simulation-based environments also engage students and promote learning. Aldrich (2004) defines simulations as tools that facilitate learning through practice in a repeatable, focused environment. Additionally, simulations are safe, flexible, resource-efficient, globally-accessible when web-based, and effective in helping students develop visual and conceptual models. *SimCity*, a popular simulation, is a good example. This simulation challenges players' strategic thinking and building abilities as they cope with resource constraints to design a harmonious city. Players can see how well their city evolves based on the decisions they make. According to Chaplin and Ruby (2005), the designer of *SimCity*, Will Wright, had deliberately left the criteria of winning and losing to the players to make their experience personal and compelling.

Even though researchers are constantly trying to define and differentiate games from simulations, there are more commonalities than differences between them. Aldrich (2004) attenuates the distinction further by recommending that educational simulations should incorporate "applied pressure situations that tap users' emotions and force them to act" (p. 9). He argues that simulations can promote full cycles of learning starting with goal, plan, experiment, feedback, update, and understanding. In a book published a year later, Aldrich (2005) prefers defining educational simulations as something that happens when simulation elements, game elements, and pedagogical elements converge. Although we are not there yet, Aldrich (2004) predicts that the development and adoption of games and simulations will have the greatest impact on teaching and learning in schools.

Educational Strengths

When designed well, both simulations and gaming environments can facilitate students' learning of both specific domain knowledge and concepts, and several cognitive skills like pattern recognition, decision-making and problem-solving. From their review of literature covering a period of 28 years, Randel et al. (1992) concluded that gaming could be used effectively to provoke interest, teach domain knowledge, and shore up retention in math, physics, and language arts when specific instructional objectives were targeted. Funk (2002) cites studies which found that games strengthened students' engagement, information processing, problem-solving, social development, and academic abilities. Other educational strengths of using games and simulations include developing a variety of cognitive objectives, transferable process skills, student-centered learning, initiative, creative thinking, affective objectives, sense of completion, and knowledge integration (Ellington, Gordon & Fowlie, 1998).

Additionally:

- Exploratory interactive games are useful for instruction in math and science, particularly when concepts are difficult to visualize or manipulate with concrete materials (Mitchell & Savill-Smith, 2004).
- Students' dialogue and decision-making while engaged with multi-level games provokes experimentation, discovery learning, and perseverance as science, technology, engineering, mathematics (STEM) principles are distorted and explored in the games (Kirriemuir, 2002).
- Students develop expert behaviors such as pattern recognition, problem solving, qualitative thinking, and principled decision-making as their individual expertise with games increase (VanDeventer & White, 2002).
- Student effectiveness increases when they are afforded opportunities to contribute to the game design and create new games (Mitchell & Savill-Smith, 2004).
- Students' motivation, skills, and ability to explore, experiment and collaborate increased by playing computer games (BECTA, 2001).
- With realistic games, students not only become smarter and intellectually engaged but also realize their desire for hard fun, delayed gratification, rewards, making right decisions, participation, depth of understanding, challenge, and using their pattern recognition and problem-solving skills (Johnson, 2005).

- Both resource-deprived and resource-affluent students, make significant learning gains after playing well-designed games (Herselman, 1999, cited by Mitchell & Savill-Smith, 2004).
- Students' spatial abilities and cognitive development increases after playing with simulations and games among both genders (Mitchell & Savill-Smith, 2004).

Possible Explanations

Computer games embody good principles of learning (Gee, 2003) and motivate players by providing them with appropriate levels of challenge, curiosity, control, and fantasy (Malone & Lepper, 1987). More specifically, what might make games and simulations so powerful for enhancing students learning?

1. Is it gamers' familiarity with the powerful visual media and gaming environments? Kafai (1996) noted that playing video games was often students' first interaction with technology in their homes.
2. Is it gamers' active engagement in structured learning environments? Rendel et al. (1992) observed that students' active participation during play could account for their better integrated cognitive structures, retention, and subsequent transfer.
3. Is it gamers' engaging experience as they interact with the different levels of game? Swartout and van Lent (2003) highlight the interplay of the three levels: short-term, medium-term, and long-term goals in facilitating compelling experiences for gamers during play.
4. Is it gamers' increased self-efficacy as their proficiency develops? Although temporary, Roe and Muijs (1998, cited by Mitchell & Savill-Smith, 2004) observed an increased sense of mastery, control and achievement in players as their individual gaming proficiencies improved.
5. Is it gamers' improved knowledge and conceptual understanding due to meaningful computer-based dialogue? Ravenscroft and Matheson (2002, cited by Mitchell & Savill-Smith, 2004) found that 30 minutes of collaborative learning through dialogue games (including exploratory talk, constructive conflict, and collaborative argumentation) produced significant improvements in students' knowledge and conceptual understanding about the physics of motion.
6. Is it gamers' ongoing learning from the immediate feedback, both successes and failures, embedded in games? According to Prensky (2001), individuals' learning through games is primarily due to the instant feedback gamers receive during play.

Challenges

While powerful and promising, the use of games and simulations present several challenges. Aldrich (2004) discusses 17 challenges related to games and simulations, including cost, delivery, time constraints, evaluation, and extent of guidance in simulations. Both the case study by Yeo et al. (2004) and our personal experiences show that interactivity and dynamic graphics in simulations, by themselves, do not promote transfer, reflection, or understanding. Meanwhile, finding and using engaging educational games continue to remain a challenge. Is this because games' efficacy and usefulness have been suspect (Wolfe & Crookall, 1998)? Are games perceived as frivolous diversions in this era of increased accountability (Balasubramanian, 2003)? Has educational computer games' limited use of sound pedagogical principles and reliance on drill and practice resulted in their being ignored in educational research (Gredler, 1996; Reiber, 1996, cited in MIT Games-To-Teach Research Team, 2003)?

Other concerns with using computer games include: difficulty of integrating games with traditional instruction, mismatch between level of game and students' abilities or needs, fear of some students not participating or cooperating, and exposing teacher vulnerabilities amidst technology-savvy students (Ellington et al., 1998). Above all, although several studies have shown the merits of playing computer games, none has addressed the classroom challenges of matching the games to the standards-based curriculum, justifying its use during premium instructional time, aligning game activity with content understanding, customizing off-the-shelf games to the learning needs of culturally diverse populations, designing authentic open-ended learning scenarios, and furthering humane values of acceptance, trust, and citizenship.

Using Games and Simulations in the Classroom – Nathan's Experience

The preceding paragraphs highlight the challenges that need to be addressed before games and simulations can become ubiquitous in classrooms. In this section, I reflect on my 16 years of teaching science and technology in middle and high schools when I have used computer games and simulations.

Four Critical Questions

What should a classroom teacher look for in games and simulations? Malone (1980) made a compelling argument organized around challenge, fantasy, and curiosity for designing intrinsically motivating computer games. Additionally, I would examine the content, quality, usability, and age-appropriateness of the game. I believe well designed games are a great asset in helping students engage and explore the core concepts in a safe learning environment, prior to formal instruction. Egenfeldt-Nielsen (2005) makes a case for using them to introduce theory and provide some concrete experience for the students. We made a similar case for using games and simulations as the first step in our conceptual framework for promoting STEM learning (Balasubramanian, Wilson, & Cios, 2005). Whether it is learning about systems and models, or examining cause-and-effect relationships, or figuring out choices and consequences, students can be quickly exposed to the big ideas in a topic by using well-engineered simulations. For example, I use the Circuit Construction Kit designed by the *Physics Education Technology Group* (*PhET*) at the University of Colorado (http://www.colorado.edu/physics/phet/web-pages/simulations-base.html) to introduce the concepts of an electrical circuit, current, voltage, and resistance. I have students explore these concepts by posing a challenge: Can you construct an electrical circuit to light a bulb with just one wire, one battery, and one light bulb and not burn the battery or your fingers? Students have opportunities to do this both online using the simulation (and not have the battery burst into flames) and hands-on with the three objects (and not have their fingers burnt). Although students are immediately engaged because they know they should be able to do it, you will be surprised by the number of students (and adults) who find this challenging.

Where should a classroom teacher look to find useful games and simulations? This has been my major concern because there is no place teachers can go to find the different games and simulations available by topic or age-appropriateness. In this era of National Digital Libraries, it would be good to have one place where teachers can access available games and simulations resources easily. I have used the *Physics 2000* simulations (http://www.colorado.edu/physics/phet/web-pages/simulations-base.html) while teaching modern physics for the International Baccalaureate program at the Emirates International School in Dubai, United Arab Emirates. I vividly recall students' fascination with this resource for testing their ideas, for example on interference and polarization, and learn more about 20th century science and technology. I also used the *Physlets*, physics applets (http://webphysics.davidson.edu/Applets/Applets.html), which are small flexible Java simulations designed for science education as a resource. *Physlets* are used by several physics teachers around the world for classroom demonstrations, peer instruction, and media-focused homework, and just-in-time teaching of introductory and modern physics. The *PhET* website at http://phet.colorado.edu hosts over 50 sims that are designed to increase student engagement and learning (Perkins et al., 2006) on common physics topics such as motion; work, energy, and power; sound and waves; heat and thermodynamics; electricity and circuits; light and radiation; quantum phenomena; chemistry; mathematics tools; and cutting edge research.

How should a classroom teacher use games and simulations? Recently I heard a counselor chuckle about a student who whined about the social studies class, asking, "Why should we study about dead people?" Researchers have used commercial games like *SimCity* and *Civilization III* to enrich their social studies classes. For example, Squire (2004) used *Civilization III* to explore its usefulness in the classroom and found that, although useful, it led to several contradictions because of the complexity of the game, extended time commitments required, students having varied difficulty learning how to use it, and different levels of students' personal motivation.

The most promising educational games and simulations I know, based on prize-winning achievements, are those designed by the Nobel Foundation (http://nobelprize.org/games_simulations.html). Students' enthusiasm for learning and playing well-designed games is captured in their rich descriptions available at http://www.innathansworld.com/technology/GamesNSimulations.htm Students repeatedly used words like learning, figuring out, paying attention, scoring, thinking, decision-making, multiple game levels, fun, challenge, interactive, strategy, hands-on, and choices in their descriptions. In my 16-years of teaching in middle and high schools, I have not seen such widespread enthusiasm for learning and sharing.

How should a classroom teacher evaluate the use of games and simulations? I was keen on finding out the ability of these games to promote student learning with minimal teacher intervention. McDonald and Hannafin (2003) noted that web-based games promote higher-order learning outcomes because they increase meaningful dialogue.

Before students played the games from a list of six, I administered a 25-question pretest electronically that provided "immediate feedback" (Balasubramanian, 2006) to students. Then students played the games for about an hour and in the last five minutes of class, I debriefed them about their experience. I gathered feedback on what they liked about these games or games in general. I consider this a brief after action review (AAR), recommended by Bonk and Dennen (2005).

In their next class, students took a post-test, with the same 25 questions. However, the order of questions was different and the tests had different titles. I analyzed their results using the Statistical Package for the Social Sciences (SPSS). The results are tabulated in Fig. 1 below.

Group	N	Pretest Mean (%)	Pretest SD (%)	Post-test Mean (%)	Post-test SD (%)	t-value	p-value
Entire Class	40	46.9	18.2	77.9	19.4	8.341	<.0001
Caucasian M.	18	51.8	19.9	80.7	16.2	6.113	<.0001
Minorities	22	42.9	16.2	75.5	21.7	5.824	<.0001
Girls	11	41.8	11.6	81.1	12.1	8.418	<.0001

Fig. 1. Summary of two-tailed, paired sample t-tests after playing the Nobel games

Clearly, despite small sample sizes and minimal teacher intervention, the two-tailed, paired sample, t-tests show that the mean test scores increased *significantly* from pretest to post-test for the entire class, even with disaggregated data by gender, ethnicity, and minority students (Girls, Hispanics, African Americans, and American Indians) classification. Clearly, my study is not a valid scientifically based research because there is no control group. However, with larger sample sizes, I could have examined whether groups of students with after action review (AAR) did better than those without AAR.

Games and Simulations are not Teacher-Proof

Evidently, designing wraparounds can be challenging. The computer games in education project (BECTA, 2001) concluded that although the benefits of using games was clear, a teacher's role in structuring and framing activities around games was critical. In the case of games and simulations designed by the Nobel foundation, it was easier for me to personally justify their use in the classroom and design quizzes to find out what students were learning. Although the games designed by the Environmental Protection Agency, (http://www.epa.gov/OGWDW/kids/gamesandactivies.html) directly related to water and the filter design activities at that time, students were quick to point out that they liked the Nobel games better. The Nobel games were "useful, exciting, fun, active, challenging, engaging, interactive, interesting, hard, and designed with very good graphics," the students wrote.

Contrary to Schank (Green, 2000), who claims that interactive software would make teachers redundant, I would argue that even with well-designed games, a teacher's role in facilitating a meaningful learning environment will remain pivotal. I would concede though that a teacher's subject expertise, understanding of pedagogy, comfort level using technology, and easy access to technology would contribute significantly to games and simulations becoming used more often in the classroom.

Recommendations

The findings of numerous researchers in this article illustrate that well designed games and simulations can prepare our students to learn critical problem-solving and decision-making skills necessary for the real world. Student endorsements that the Nobel games and simulations actually "teaches you about the subject, uses harder questions and better graphics," along with results from their pretests and post-tests showing significant gains, illustrated how students are not averse to learning in the classroom. Further studies might explore what makes these Nobel games and simulations interesting.

Evidently, games are firmly entrenched among youth and adults alike, as the recent BBC Audience Research study reported. When designed well, games can truly be an important teaching tool (Shreve, 2005). They promote numerous cognitive benefits in learners, including a facilitation of increased interactions, motivation for learning, visualization, experimentation, self-efficacy, self-monitoring, pattern recognition, problem-solving and critical thinking – abilities that we want all our students to graduate with from our schools.

Yet, several educators continue to view the use of games and simulations in the classroom with apprehension. If games and simulations are to be meaningfully integrated into classrooms, the following five guidelines should inform the design of educational games in the future.

1. The design of games and simulations should be sophisticated and challenging enough for students to be cognitively engaged with the game.
2. The content of games and simulations should be aligned with the standards and viable curriculum in schools.
3. The logistics and usability of the games should reflect classroom realities and time constraints in schools.
4. The feedback and assessments embedded in the games should embody measurable learning outcomes.
5. The teacher guides accompanying the games should provide sufficient ideas, activities and resources to enhance students learning.

The papers that follow provide more examples of how games and simulations might be used to enhance learning in classrooms.

Chapter 6

NURTURING TEACHER EXCELLENCE USING THE LEARN BY DESIGN MODEL (LBDM)

How might schools with large populations of students from low-income, migrant, and international families ensure that *every* student reaches proficiency "on challenging State academic achievement standards and state academic assessments (NCLB, p. 1439)? Traditionally, schools across the country have tended to cope with this challenge by offering a narrower range of curriculum and focused only on improving students' "low level literacy" skills (Bransford et al., 2000) – reading, writing and mathematics – because currently only these results get reported in the Federal School Accountability Report (CDE, 2006).

In this article, we share preliminary results from our systemic school-wide curriculum reform effort using an evidence-based instructional model to cope with challenges at Overland High School (Overland) located in the Cherry Creek School District in suburban Denver. Overland is a comprehensive public, suburban, college-oriented high school with a total enrollment of 2,153 students in the 2007-2008 school-year. Over 2000 students have been enrolled in the school each year since 2000-2001. Over the past 6 years, the school has undergone major demographic changes. Specifically, the student community has changed from a predominately Caucasian, middle-class to an international, minority-majority school. Students at Overland represent over 60 countries and speak over 54 different languages. The student community includes a diverse population from different social, economic, ethnic, and racial backgrounds, with 37.1% identifying themselves as African-American, 33.7% Caucasian, 22.1% Hispanic, 6.3% Asian, and 0.8% American-Indian. In addition to the ethnic diversity, the school now has a poverty rate of 41%. While college preparedness and academic excellence are hallmarks of the school district, student performance at Overland has continued to decline over the past six years when compared with the state and district performance (Exhibit 1).

Overland's campus also includes a feeder middle school, Prairie. The demographics of the two schools are similar as both schools have students from the community that surrounds our campus. Given these overall trends, the achievement of the 2000 cohort (Exhibit 2) and 2001 cohort (Exhibit 3) of students, during their five years as they move from middle to high school, shows a stagnant and declining trend across the two schools.

DiMartino, Clarke, and Lachat (2002) have written about the futility of making students learn factual knowledge where students are merely "listening to lectures, waiting, taking tests, and doing seat work" (p. 45). These students learn fewer life-skills because of limited intentional opportunities to develop their higher-level literacy skills (HLS). Consequently, they will continue to perform poorly on state assessments that test students' HLS. This leads to lower faculty, student and parent morale. Yet, research on how students learn has shown us that using an explicit PLAN → TEACH → MONITOR → ADJUST instructional model with rigorous curricula that provide opportunities for teachers to learn effective instructional strategies, have structures in place for their mentoring, use active monitoring and have accountability measures in place, can raise the achievement of every student (Balasubramanian, Wilson & Cios, 2006; CCSD, 2007; Grier, 2002).

Learn by Design Model (LBDM)

In this section, we describe our conceptual framework for developing and nurturing teacher excellence to increase student achievement. The Learn by Design Model (LBDM) is an evidence-based instructional intervention that is grounded in cognitive and neuroscience theories on learning and motivation (Bransford et al., 2000; Goleman, 2006). The model has two components (Exhibit 4). First, this model operationalizes Wiggings and McTighe's (2005) *backwards design* by using an embodied theory – a specific template of activities and protocols – to align curriculum, assessment and instruction to promote student-centered learning.

Second, to develop students' higher-level literacy skills (HLS), this model operationalizes five HLS – critical thinking, problem-solving, mathematical reasoning, inference-making and visualization/modeling (see examples across the four core subjects at http://www.doers.us/HLS_Defined.pdf) – so teachers can explicitly plan, teach and monitor student learning of these essential life-skills.

In order to create a Professional Learning Community (PLC) for this model, we asked for teacher-volunteers who would teach the freshman class during the 2007-2008 school-year. Two administrators and two faculty members were the lead-trainers for this PLC. The lead-trainers then worked with these teachers to provide them with 25 hours of face-to-face professional development (available on 5 DVD's). 13 teacher-leaders across four subject areas – English, mathematics, science and social studies – were trained on the LBDM in summer 2007. To demonstrate their understanding of LBDM, these teachers were asked to develop curriculum plans for the first quarter of the 2007-2008 school-year and submit them to the Principal. These curriculum plans were then graded independently by the lead-trainers using a 100-point grading rubric. The mean was 83% and the Kuder-Richardson 20 coefficient was 0.9752, showing the close agreement between graders. The pretest(47%)–post-test(73%) gains with a Pearson's r correlation of .799 showed that 89% of the variance in the post-test scores could be accounted from the LBD training. Further analyses of these summary results are available at http://doers.us/LBD_FAQs.html The 13 teacher-leaders started implementing their curriculum plans in August 2007 and now teach over 670 students (approximately two-thirds of the combined freshman-sophomore classes at Overland). We plan on continuing with the implementation of LBDM with the freshman class this year and then scale the project to include the other three grade levels by adding one grade level each year over a four year period.

Unique Features of LBDM

Although the implementation of LBDM is in its early stages, we want to share the unique features and results of our systemic curriculum reform initiative at Overland because it could help increase student achievement in other schools. As we describe these features, we quote extensively from teacher-reflections at our training sessions to illustrate how we developed teacher excellence as they became "co-creators of knowledge" with us and emerging as teacher-leaders.

Emphasis on Writing

Even before teachers formally instruct their students, LBDM requires students to think and respond to *real-world scenarios*. This writing activity not only challenges students but it also gives them an opportunity to demonstrate their learning of standards-based content in their own words. After acknowledging the importance of "acknowledging and deflating student misconceptions", one teacher wrote that these prewrites "identify incomplete understanding, false beliefs and naïve rendition of concepts," prior to formal instruction. While the prewrites give students a *purpose* for learning, at the end-of-a-unit when students are given a similar but *different* scenario for their post-write (see Overland Unit Planner exemplar for an example http://www.doers.us/Sample_Unit_Planner.html), teachers know how well students can generalize and transfer their learning. Besides, the explicit focus on writing prepares our students for college (Conley, 2005) as they demonstrate their "communication, reasoning, personal interaction, and quantitative thinking skills" (p. 135).

Growth Model

While all our teacher-leaders acknowledged the importance of pretests to show measurable student growth and progress in their reflections, they articulated other benefits for students including: helping "students know where they are and where they need to be by the end of the unit or chapter," "could help with increasing self-esteem," "be more self-guided," "be more accountable for their learning targets," and "help motivate the students." Teachers also said the pretests are "a tool that is integral in differentiating the instruction for the unit," "the pre-test data can help drive my instruction for the unit by utilizing existing student strengths and weaknesses," and "assess student learning and the effectiveness of teaching methodology." These reflections are consistent with essential learning goals that are personal and relevant to students as described in the third core area of *Breaking Ranks II* (NASSP, 2004).

Intentionality

Hands-on guided-inquiry learning, as valuable as it is, must be connected to the established content in the "standards." The revised two-dimensional Bloom's Taxonomy (Anderson & Krathwohl, 2001) is useful to plan and organize the cognitive elements of instruction so students could easily see the transition from simple to complex levels of thinking. Reflecting on the purpose of planning their learning outcomes using the revised taxonomy, teachers wrote: "The 2D Bloom's Taxonomy forces you to decide the type of knowing that your students are doing in addition to their level of thinking," "Students will learn if they know what it is that they are expected to learn," "This is important because students should not be able to only draw on factual knowledge. They should have to draw upon other types of knowledge," "To make sure that the frameworks are being addressed, but also, that you are designing this for more complex levels of Bloom's taxonomy for your test and unit design," "To make sure that you are asking the students to think and know the content in multiple dimensions, some at the lower levels and some at the higher levels. It will help ensure that I get to HLS and use multiple assessment formats," "This allows me to more effectively analyze the different levels of thinking going on in my classroom." Developing this epistemological understanding, helping students understand the value of creative and higher-order thinking, is a valuable learning outcome in its own right (Balasubramanian & Wilson, 2007).

Value-added

While it is important to have students know and be able to do things, it is critical that our students value learning and its connection to the real-world. The initial inquiry scenario through simulations and/or hands-on activities is designed to **engage and motivate** students as they begin their formal study. Reflecting on its importance, teacher-volunteers wrote: "It grounds the facts and skills in a real-world application that allows students to see the necessity of what they are learning. It also sets up the direct instruction that might follow," "Students may discover something new on their own" Also, the inquiry scenario "may help students develop their own questions they want to explore further," "Teenagers are naturally competitive, we should use this desire in our favor, this will increase engagement throughout the course," and "students gain more ownership of the content. Any step that helps students to THINK is a valuable tool."

Formative Assessment

This is a significant part of the embodied theory and the driving question: "what **evidence** will you accept that students value, know and are able to do" in your class led one teacher to reflect on this new understanding because it now "has opened up the whole idea of assessments as learning tools." Others said: "It will help me to create better assessments and to use my assessment scores to adapt my teaching," and "I now understand the difference between "assessment for learning" and "assessment as learning"."

Backwards Design

An emphasis on targeted and intentional teaching of curriculum is meaningless without well designed diagnostic, formative and summative assessments. Our teacher-volunteers received *extensive* training in aligning assessments with instruction and how to use the assessment results. Initially, they were asked to bring in a current assessment for a unit. They then looked at these assessments in many ways. First, they examined the amount of time spent on each topic within each unit and how this correlated with their assessment. We also asked them to look at the quality of their tests. Incorporating higher-level literacy skills (HLS) into instruction is a fundamental component in LBDM. If HLS is taught, they should be assessed as well. Simple comparative matrices showed that most tests that teachers brought were written at the factual and recall level. After instruction on how to write quality assessments, the items on diagnostic, formative and summative assessments *changed dramatically*. With this paradigm shift, teachers then spent a considerable amount of time rewriting exams, aligning instruction and incorporating feasible higher-level thinking questions for the school's common assessments. Finally, the teacher-leaders used simple item analysis rubrics to align test items with their instruction. A good understanding of backwards design is foundational to the best practices discussion that teachers must have as they continue to improve classroom instruction based on student performance in the common assessments.

Metacognition

Throughout the LBD Model, both teachers and students use an the iterative metacognitive cycle **STOP** → REFLECT → THINK → ACT to actively promote *teaching for transfer*, where students use the knowledge gained in one subject to apply it to not only that subject but also to other subject-disciplines. One teacher summarized: "The teacher must have clear goals as to WHAT and HOW the kids are going to learn. It is important to think of assessment as three dimensional and ongoing. Assessment is for the students too. Students need to learn how to assess themselves and how to grow in their own learning. This is the metacognitive piece that is essential to the LBD Model." Another wrote: "As you move towards LBD instruction, you are creating a learner-centered classroom that is positive, engaging, and one in which students receive feedback everyday in different forms. It also allows teachers to assess in many different ways."

Challenges and Next Steps for Measuring Effectiveness

It takes a huge amount of resources to implement the explicit PLAN → TEACH → MONITOR → ADJUST instructional model. Teacher training, curriculum development and reflection take time and require financial and human resource support from the school and the district. It has been a challenge helping teachers move away from a teacher-centered to more student-centered learning in their classrooms. Although our inter-grader reliability was very high, to make sure the lead-trainers knew what they were looking for as they evaluated teachers' curriculum plans took time. Keeping up with all the communication and follow-up required, amidst the lead-trainers' normal work schedules has been difficult. The huge expectations, including reporting pretest data and monitoring progress on student learning every three weeks, although valuable, is very time intensive. As we look forward to our next steps, we want to analyze these pretest results and share it with our emerging teacher-leaders. We want to see how these pretest results and classroom instruction impact student performance and how they correlate with our state academic assessments. Using these results we would modify not only teaching but also the implementation of LBDM. Additionally, we would like to include more faculty from the school across the freshman and sophomore classes. We will continue collecting data and use it to evaluate instructional effectiveness. Articulating with the feeder middle school is one of our next goals. Despite all these challenges, we gain strength from the preliminary results of our faculty training. The commitment, ownership and enthusiasm of these early-adopter teacher-leaders in implementing this school-wide systemic intervention is inspiring.

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ProQuest Digital Dissertations. (No. AAT 3293506)

SUPPLEMENTARY MATERIAL

Summary Results compiled from Federal School Accountability Reports.

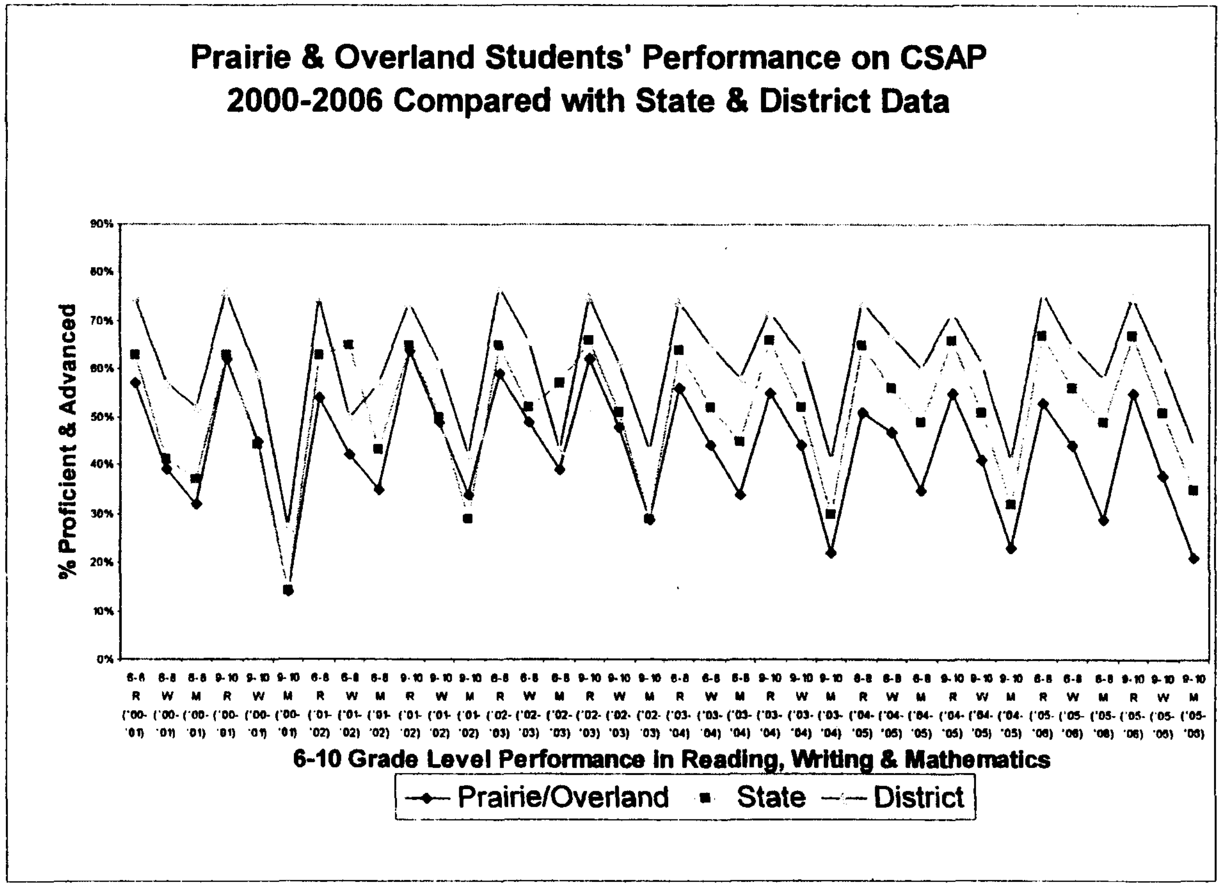

Exhibit 1: Student performance in reading, writing and mathematics since 2000

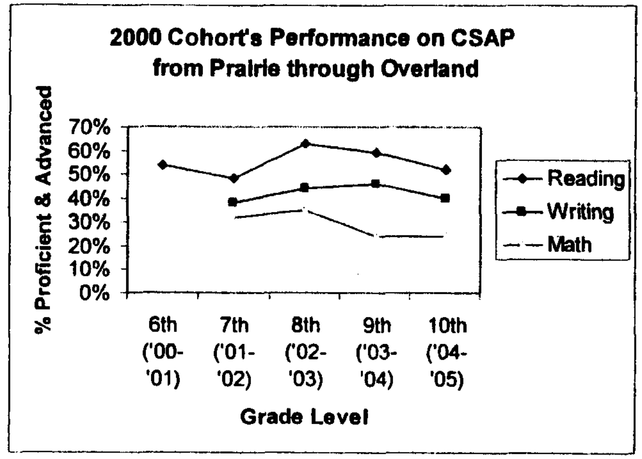

Exhibit 2: 2000 Cohort of Students' Progress over time

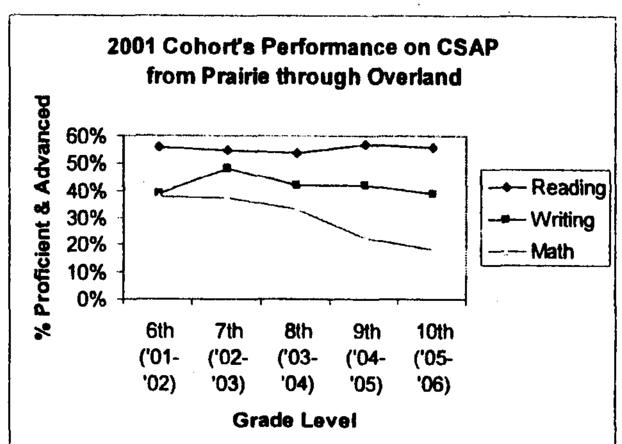

Exhibit 3: 2001 Cohort of Students' Progress over time

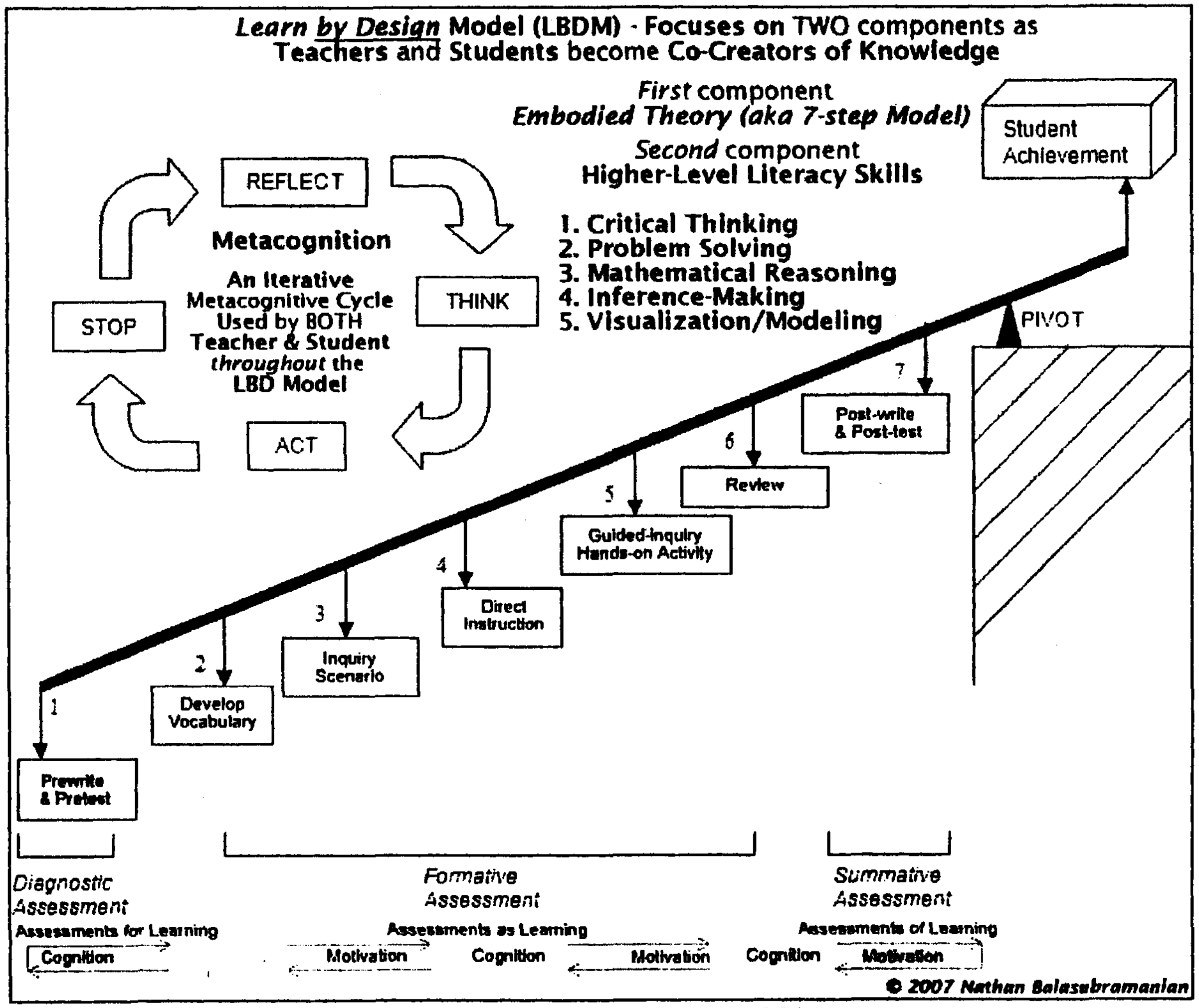

Exhibit 4: Learn by Design Model (LBDM)

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