Designing effective instructional models for increasing student achievement

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Learn by Design Model

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

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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.

1. 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; 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.

2. 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).

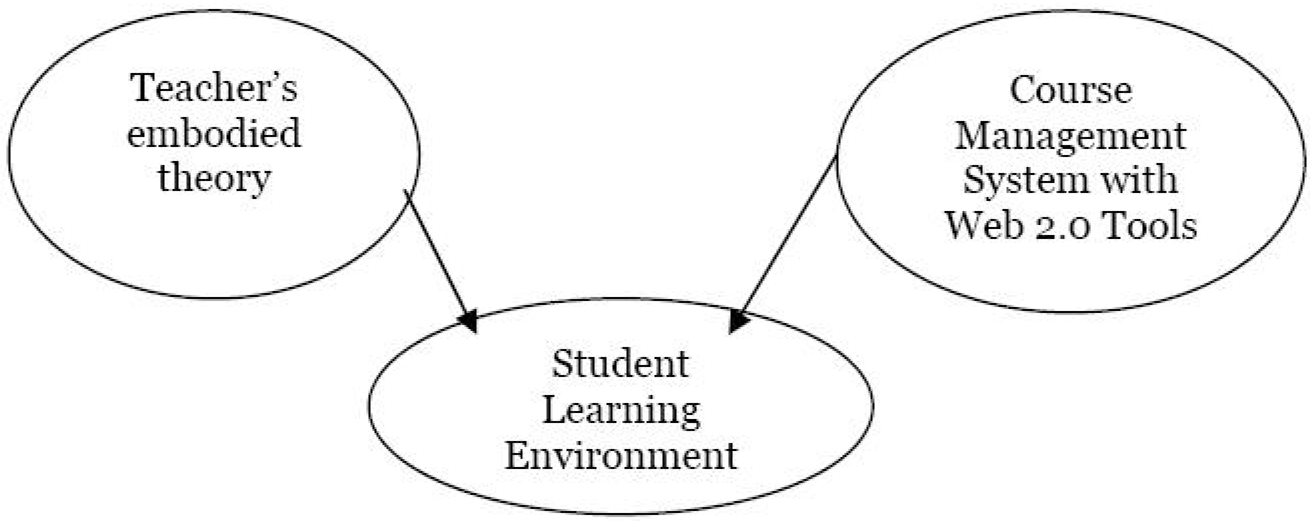

Fig. 1. Creating meaningful technology-mediated learning environments

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).

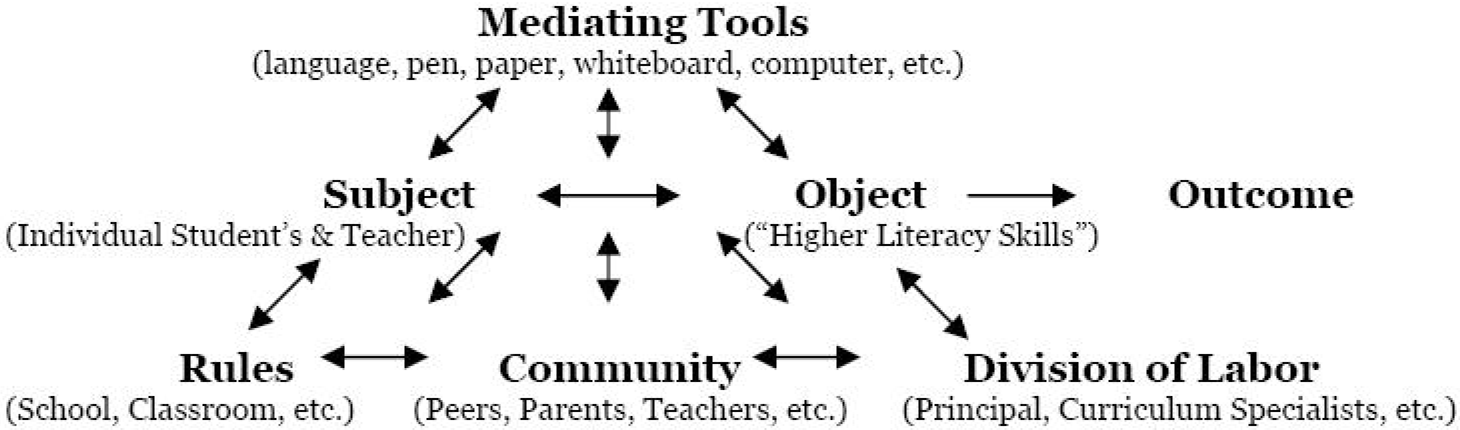

Fig. 2 Cole and Engeström's activity theory framework (adapted from Bellamy, 1996, p. 126)

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.

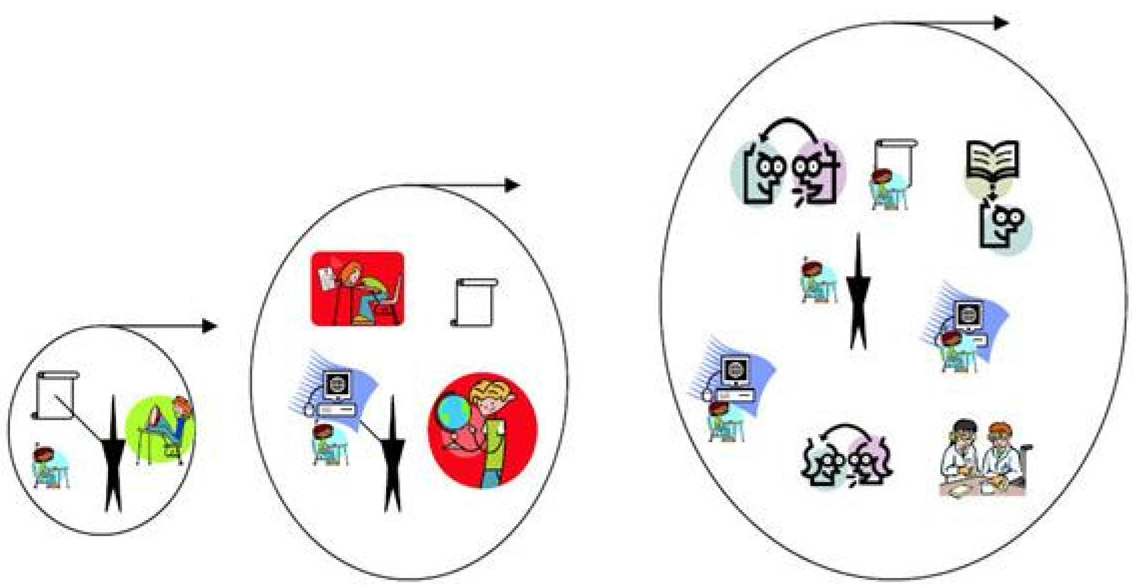

Fig 3. Student learning environment as an evolving activity system

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.

3. NATHAN'S JOURNEY – A CASE STUDY

3.1 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.

3.2 "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.

3.3 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.

3.4 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.

3.4.1 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.

3.4.2 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.

3.4.3 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). The 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.

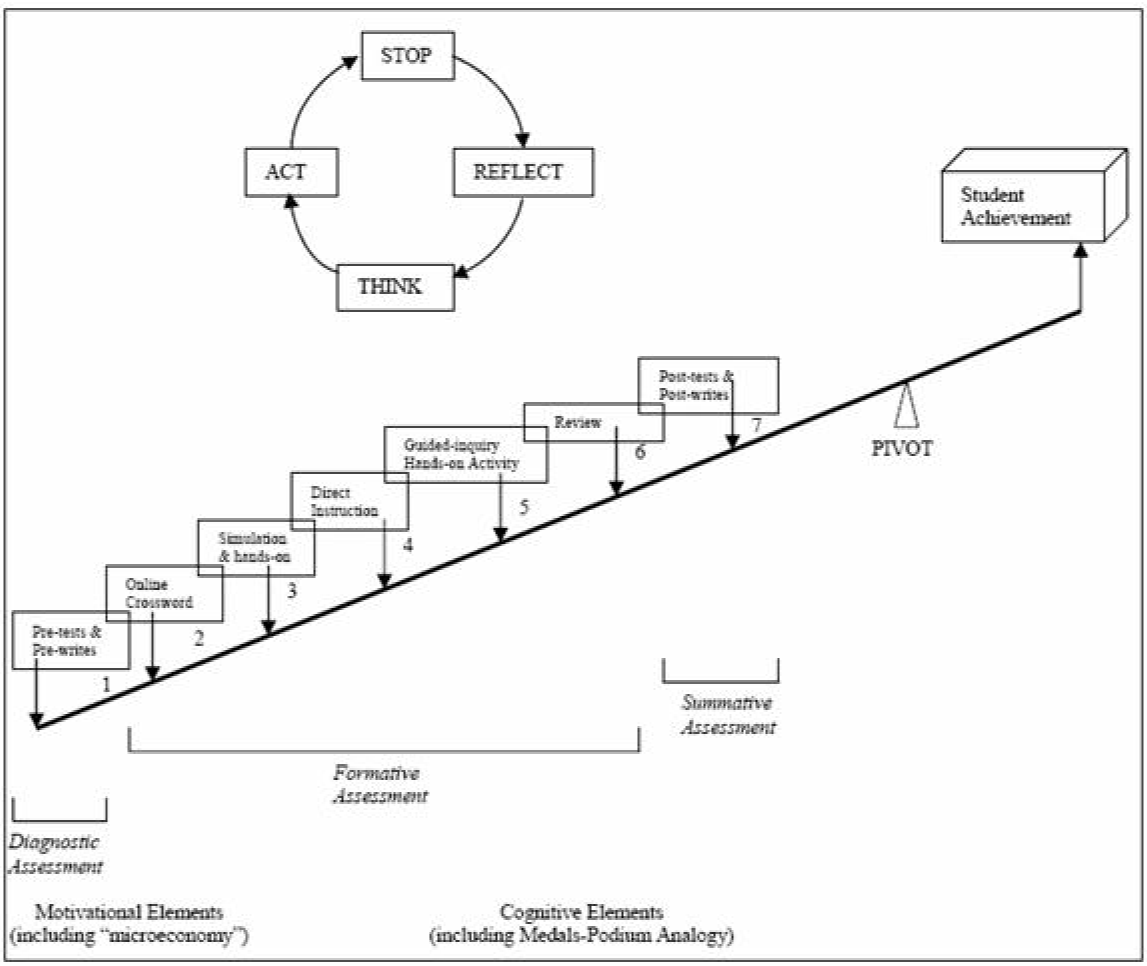

Fig. 5 Embodied theory for increasing student achievement

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.

4. RESULTS FROM A PILOT STUDY IN NATHAN'S CLASS

4.1 Facilitation, Teachable Moments & 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.

4.2 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 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.

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	5.556	<.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)

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.

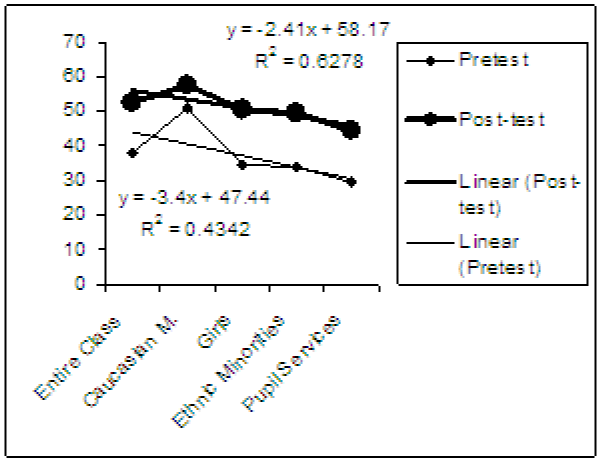

Fig. 8. Pretest and Post-test scores of four subgroups in the 18-item hydrologic cycle test in the filter project, before and after direct instruction

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.

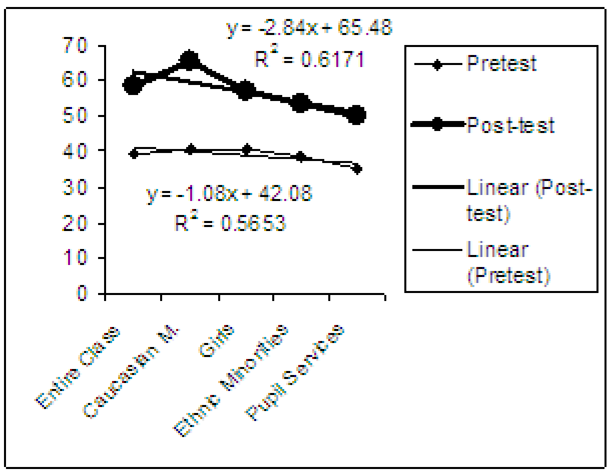

Fig. 9. Pretest and Post-test scores of four subgroups in the 42-item water test in the filter project, before and after guided-inquiry hands-on activity

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, 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.

5. 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.

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