Innovation and Reliability in Engineering Education: A Both/And Possibility

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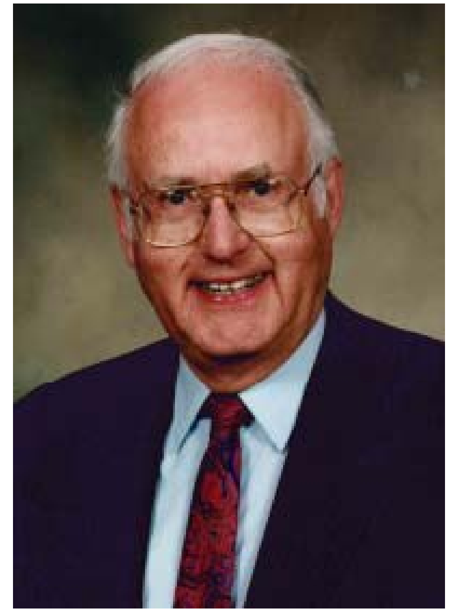
Dedication



- Don Woods, first 3M cohort, passionate mentor and innovator, visionary educator in Creative Problem Solving and Design *(d. 2013)*
- Tyler Heal, UofA class of 2013, social and technical innovator, engineering art promoter (*Spaces)*, Engage North, EWB

Once the light has been turned on, it doesn't matter how long the room was in darkness.

...and there is a no returns policy on enlightenment!

...a small problem...

pg xv Most of us have “absolutely no idea what kind of instruction is required to produce students who can think critically and creatively, communicate effectively, and collaborate versus merely score well on a test.”

pg 18 “...every student starts school with unbounded imagination, curiosity and creativity – until they learn that knowing the right answer is far more important than asking a thoughtful question.”

The difference today is that there is a glimmer of insubordination in this generation. Our students will find a compelling teacher on the internet or among their own networks if we fail to provide what they need in the classroom.

Creating Innovators, Tony Wagner

The Full on Solution

- Parents that provide open ended experiential learning and experiment, unconditionally supporting their children's curiosity and directed play, fanning it into a passion, and teaching them that they can make a difference in the world.
- An iconoclastic mentor or instructor, who provides hands-on design and innovation experience in teams from widely diverse backgrounds, ideally set up with resources and the maximum challenge with a finite time frame to complete the project. The students learn passion and intrinsic motivation.
- All of the research converges on this model. Randy Pausch's Last Lecture is a great exemplar story of the point.

Teaching Innovation: A Few Possibilities for Real People

- *Small AND Powerful* – the synergy of opposing values
- *Learning to fail* – the importance of resilience
- *Building core skills* – some robust technical tools
- *Why?* – building curiosity and critical thinking
- *Becoming values driven and strategic*

1. Finding Synergy in Opposing Values

based on a tool presented in the workshop by Russ Gaskin,
EWB National Conference, January 2013, Calgary

Where are we now?

What words might engineers use to describe these opposing values?

+

• safe • low risk • reliable and trusted • wide base of experience • predictable • High Chance of Success	• paradigm shift • breakthrough in technology • disrupts complacency • joyful creative work • satisfies future need • Big Payback
Reliable	Innovative
• boring routine implementation • stuck in the past • lower profit margins • does not meet current needs • leads to obsolete product	• unknown, frightening, stressful • more work to implement • proponents *can't be trusted* • no experience, no rigorous data • Risk of Failure and Loss

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Do we actually want innovation in engineering?

Where we are now

Do we actually want innovation in engineering?

- safe
- low risk
- reliable a…
- wide base o… …ce
- predictable
- High Chance of Success

Strengths

- para…
- dis…
- brea… …nology
- satisfies future need
- **joyful creative work**
- Big payback

Weaknesses & Opportunities

Reliable | Innovative

- boring routi… …mentation
- stuck in the…
- lower profit …
- **does not meet current needs**
- **leads to obsolete product**

Blind Spot

- unknown, …ighte…ing, str…ssful
- more w… …nt
- prop… …sted
- no exp… …, … …orous data
- Risk of failure an… loss

Visible Risks

Weaknesses and blind spots suggest further consideration.

What might be possible

When opposing positive values are successfully paired a sort of nuclear fusion takes place that releases enormous amounts of value and potential.

- safe
- low risk
- reliable and **trusted**
- wide base of experience
- predictable
- High Chance of Success

- paradigm shift
- breakthrough in technology
- disrupts complacency
- **joyful** creative work
- satisfies future need
- Big payback

Reliable **AND** Innovative

- **boring** routine implementation
- stuck in the past
- does not meet current needs
- leads to obsolete product
- lower profit margins

- unknown, **frightening**, stressful
- more work to implement
- proponents **can't be trusted**
- no experience, no rigorous data
- Risk of failure and loss

Notice some of the key words...

and what might come out of that...

Embracing the other gives a modified list with fewer down sides:

- safe
- **reliable and trusted**
- well validated
- predictable
- **leverage existing experience**
- **easy to implement, robust**
- evolving to meet current needs
- High Chance of Success

- breakthrough in technology
- **joyful creative work**
- paradigm shift
- gather data, experiment
- **be critical, iterate, ask Why?**
- **failure is part of the process**
- satisfies future need
- Big payback

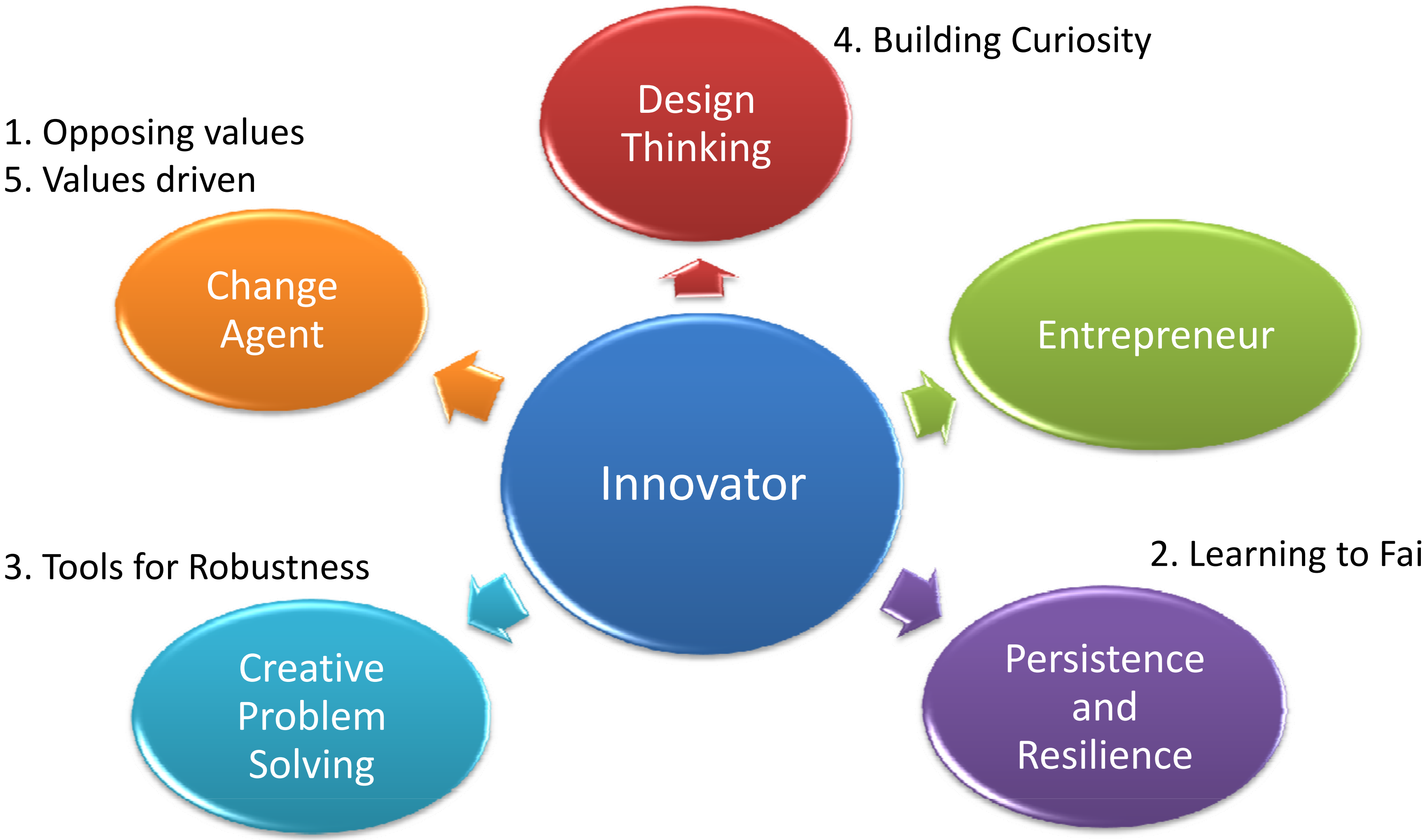
Reliable **AND** Innovative

- **invest in learning and improving**
- guard against obsolete practices

- **build trust, be values driven**
- minimize risk

Real success means putting your profit back into continuous innovation.

Characteristics of Innovators




Innovator
Creative problem solving
TRIZ
Changing Perspective
Structured Brain Storming
Explore
Plan and Gate
Implement
Review
Celebrate
Access and Analyse Information
Define
Engage
Communication
Challenge the Status Quo
Empathy
Resolve conflicting values into synergistic values and shared purpose
Build trust
Identify Sources of Acceptance and Resistance
Entrepreneurship and Initiative
Market
Financing
Manufacturing
People and facilities
Strategy and business plan
Sales
Perseverence and Resilience
Empowered
Agile and Adaptable
Play, Passion and Purpose
Testing - first fire bullets
Risk taking
Clear vision and values
Fail fast and fail often
Design thinking
Empathy
Integration
Collaboration
Optimism (solution exists)
7 Levels of Change
Experiment and Refine
Curiosity - power of Why?
Stepping out of context

Existing Programs

- Waterloo Accelerator Center – Research Innovations
- McMaster Center for Entrepreneurship and Innovation – MEng/MBA
- Industry Based Design Projects at UofA – 4th year, 2 courses
- Poly Montreal Integrated Transport – 3rd year, full term
- Lab plus design project at UBC – 3rd year
- MecE design at UofA – 2nd 3rd and 4th year
- What's in the Box? at the UofA – 2nd year
- Inverted classroom and 1st year design – UofT – 1st year

- Remarkable success on US Fundamentals of Engineering Exam

2. Teaching Innovation

Play, Passion, and Purpose

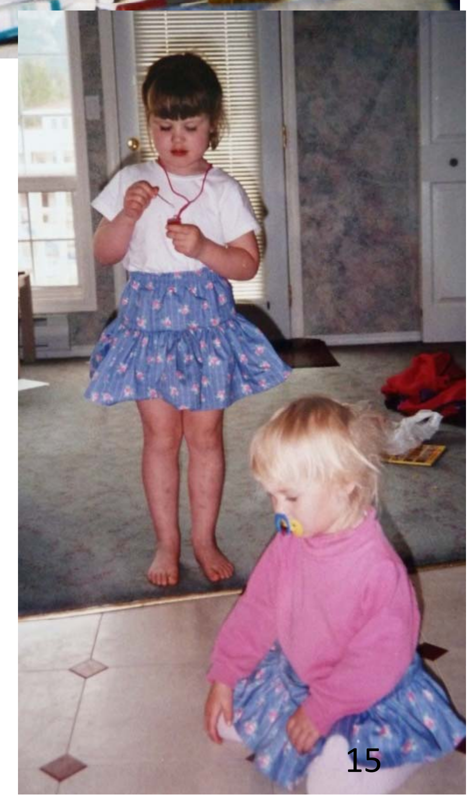
Learning to fail as a natural part of the creative process

Steps in Development

1. *Baby Steps; Developing basic skills*
2. *Initiative and Drive; Intrinsic motivation*
3. *Resilience; Learning to fail*
4. *Mastery and Flow*
5. *Concept transfer and innovation*
6. *Collaboration*

1. Baby Steps

- Early courses build skill sets.
- Begin with a high standard of performance to build a solid foundation.
- Integrate skills into a larger goal.
- The envelope needs to be drawn small enough to ensure a first taste of success (*1st year community design experience, Univ. Toronto, S. McCahan).*



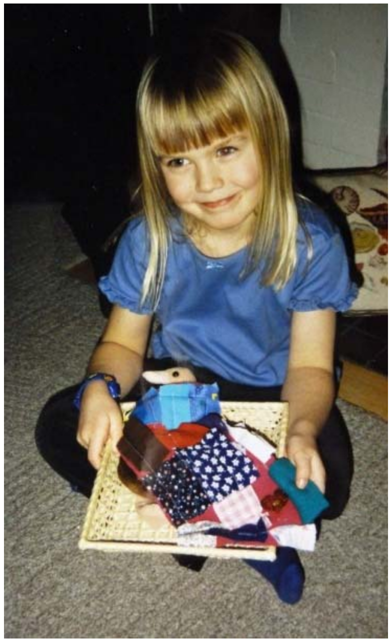
Ages 2 and 5

2. Initiative and Drive

- Given a first taste of success, students will run with the ball and take ownership.
- Their efforts will not always be what we expect, but at this stage they learn a lot about how to fail, how to test ideas, and the importance of iteration and accuracy in design *(Pierre Mertiny, 2nd year MecE design, Univ. of Alberta)*.

The most important thing is allowing them to ask questions, and then giving them the space to find the answers.

Age 5



Age 5

3. Resilience

Age 6-7

Learning to Fail

- Failure is part of creating new and amazing things.
- ***In the one-right-answer world, mistakes are costly, embarrassing disasters (which could kill someone).***
- Individuals MUST be allowed to fail and recover in order to learn to innovate.
- ***In the innovation world, failure is an important part of a natural process that clears the path to success.***
- What kind of engineering do we teach today, based on how we grade our courses and assignments?

How to shift this?

- What if we were to provide the students with failures to fix, based on their technical understanding and their prowess with problem solving and math??? (McMaster Troubleshooting)
- What if classroom examples included problems where they were to find the errors in assumptions or execution or design?
- What if we set them up to fail and recover as part of the design process??? (Scoping reports early in the process)

The Journey

“One of the most powerful lessons of the innovators I’ve met, whether young and idealistic or old and methodical, is that they’ve enjoyed the journey not *despite* its difficulties, but almost *because* of them. They relish not only the war stories but also the actual one-step-forward-two-steps-back dance of innovation. To them, it’s fun. They don’t always win, but they are always engaged and fully alive and curious about what will happen next.”

pg 184, Amanda Lang, The Power of Why?

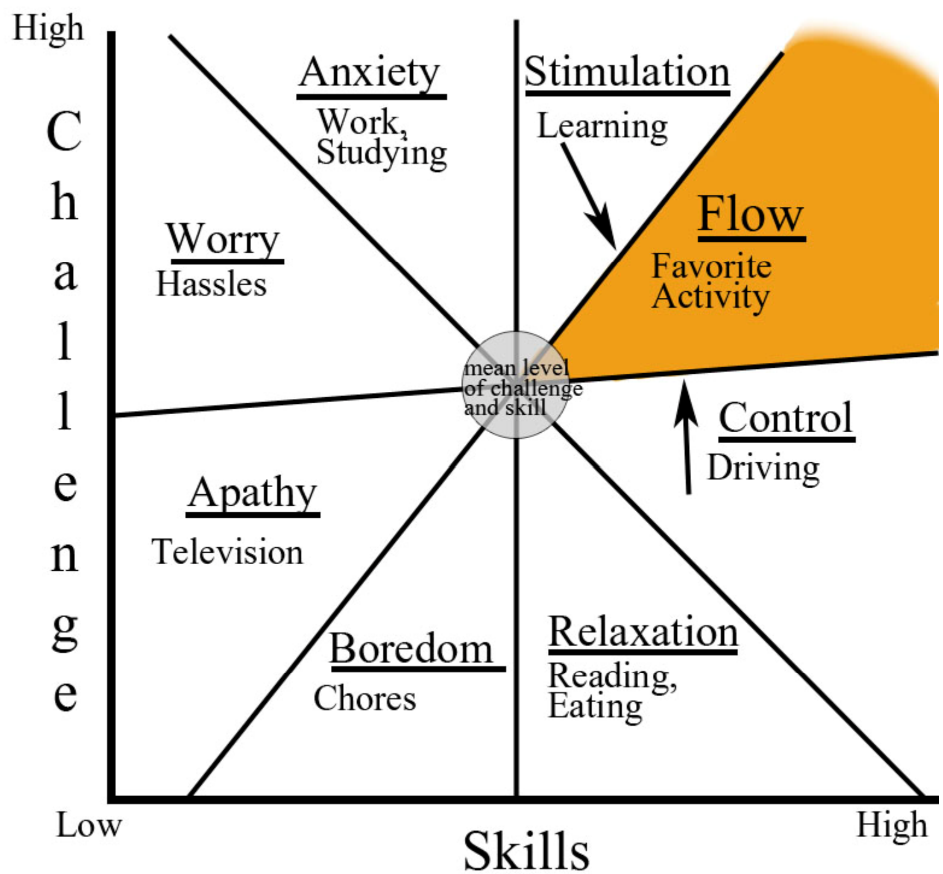
4. Mastery and Flow


Age 8-9

At the point of mastery, work becomes a flow experience. Time stands still and the balance of challenge and skills is ideal.

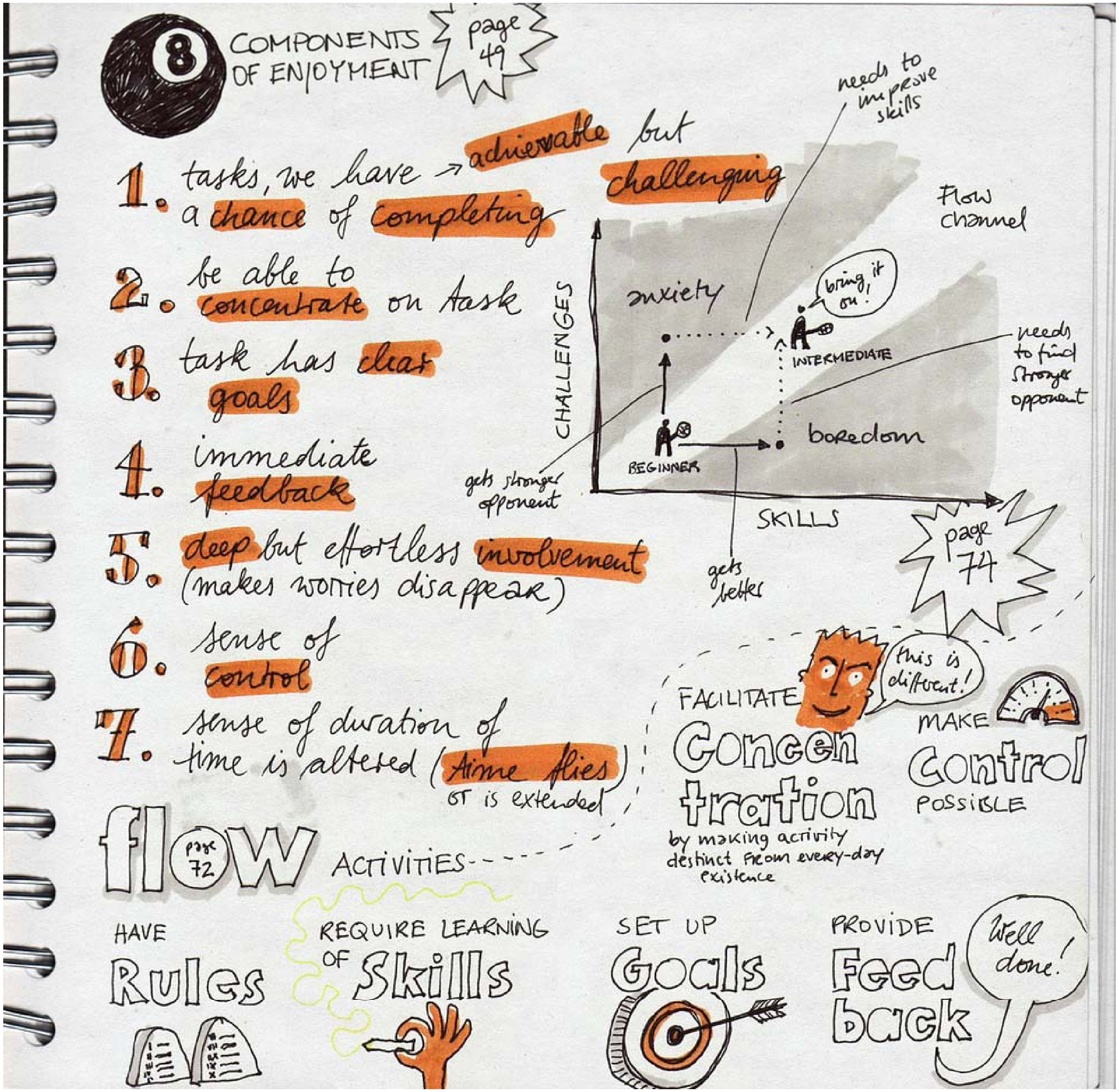
The Experience of Flow

- Flow requires balance between skills and challenge of the task.
- Flow activities:
  - have rules
  - set up goals
  - require learning
  - facilitate concentration
  - provide feedback
  - make control possible



http://mraybould.wordpress.com/2013/04/

Visual summary of the book Flow.



Bonus slide for handouts.

http://loymachedo.com/book-reviews/loy-machedos-book-review-flow-the-psychology-of-optimal-experience-by-mihaly-csikszentmihalyi/

Modelling a Lack of Cynicism

"Innovators retain...a childlike sense of optimism. They've managed to hang on to a sense of wonder about the world and a belief in their own ability to have an effect on it. They're persistent and stubborn about reaching their goals, but flexible and open-minded when it comes to figuring out how to get there."

Yup.

Amanda Lang, The Power of Why?, pg 114

5. Concept Transfer and Innovation

I want to paint my ceiling.

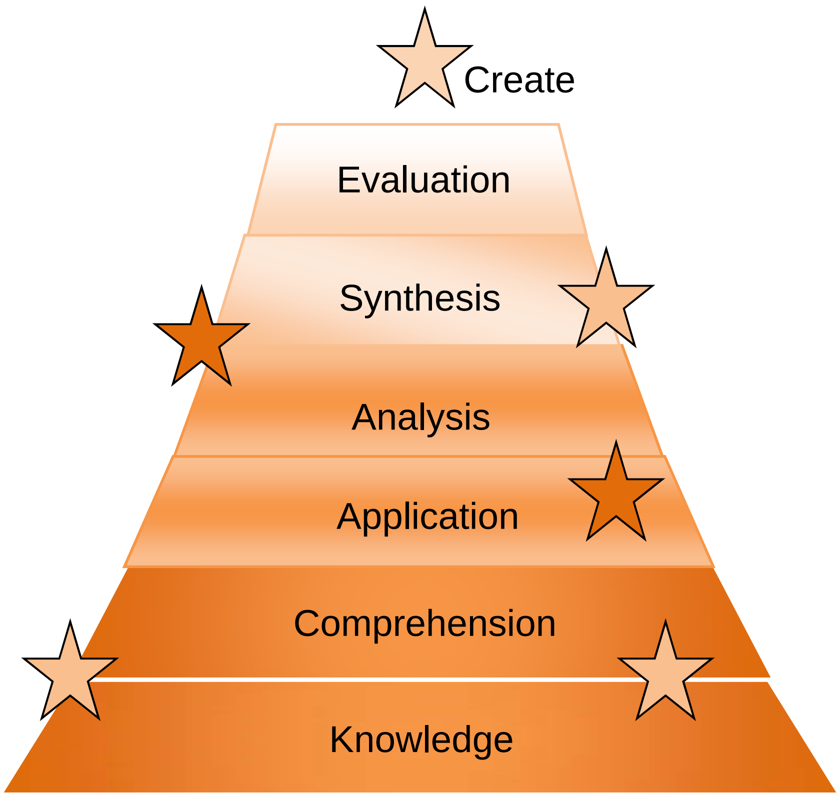
How many colors of paint can I buy?

Skills Transfer

- One learning objective we value is the ability to transfer understanding from one scenario to another.
- The *concept,* and the *transfer* of concept to a new application are *different skills.*
  - *Holyoak and Novick (1987) showed that three examples of change of context are needed for students to be able to transfer successfully themselves.*
  - *Focus on the key points and the underlying formalism – repetition is not a bad thing.*
- The *innovation* step, where the concept and skill are transferred to an entirely new problem, is now placed at the TOP of the Bloom scale, as create.

Rob Goldstone, 2009, Gordon Conference on Visualization in Science and Education.

Bloom's Taxonomy



Create in the top star means the creation of new knowledge.

Innovation is most powerful when the inputs are diverse, and not necessarily expert.

Teach the 7 Levels of Change

*Innovation is **not** a light bulb moment!*

1. Do the right things to get where you need to go.
2. Do things right.
3. Do things even better.

4. Do away with things.
5. Do things others are doing.

6. Do things no-one else is doing.
7. Do things that can't be done.

Rolf Smith, 7 Levels of Change - Third Edition: Different Thinking for Different Results

6. Collaboration

Ages 20 and 17

- The last stage of maturity in innovation seems to be a willingness to collaborate.
- "In almost the same way that emotional maturity involves growing out of childhood egotism, intellectual maturity might involve realizing that ours is not the only way of thinking." pg 209, Lang
- Overseas work placements, engaging in another language and culture give the experience of being an outsider needing help and making oneself understood. People with these experiences are consistently better innovators. (The EU now requires this experience of all engineering students.)

3. Tools for Robustness

Some observations and comments from my last sabbatical at CoSyn engineering

Basic Tools

- Units
- Rough estimates
- Drawing the problem
- Clear communication and problem definition
- Numerical accuracy
- Using good exemplars of solutions

Structured Problem Solving

- Organizing data in a clear and standard format with standard notation (e.g. material balance table with stream numbers)
- Writing out assumptions
- Providing clearly laid out solutions

❖ When students are learning a new problem, they can often move through the first stages much faster by using a table to help structure their thinking!

Airplane Pilots use Checklists

- Detailed design in industry uses specification sheets to ensure that all of the aspects of the design have been checked and signed off.

❖ What if we used a modified version of this idea for our courses?

  - Is there actually value in having them try to remember all of the aspects of a problem solution in random order??

  e.g. Heat exchanger design.

❖ If we got this out of the way, could they spend more time thinking about whether the solution makes sense? *(Yes!)*

Spreadsheets – Design, Build, Debug?

- There are a few problems here that we are ignoring!
  - Spreadsheets are widely used in industry
  - Academics criticize their numerical stability etc.
  - On the whole, students design them badly and get no instruction or feedback!
- Does this have a place at the end of a course?
- How would we teach robust design of spreadsheets?

Taking Enough Time

- In a multi-million dollar project, engineering time is cheap and getting it right is critical to the success of the project. Cross checking and rechecking using design protocols and two independent sets of eyes is standard and best practice.
- Students and professors have no time and no resources. This is an interesting dilemma!

❖ Having students work in pairs and sign off each other's work is a solution we might want to use and develop further.

  - immediate feedback, critical thinking, teamwork, robustness, empowerment, intrinsic motivation

Intrinsic Motivation

What I want to hear from our graduates:

- I WANT feedback. It helps me to get better and to learn.
- THANK YOU for teaching me that ripping it out and trying again is an important part of getting something that you can love and be proud of.
- The 80/20 rule is a really bad idea for engineering projects.

4. Building Curiosity

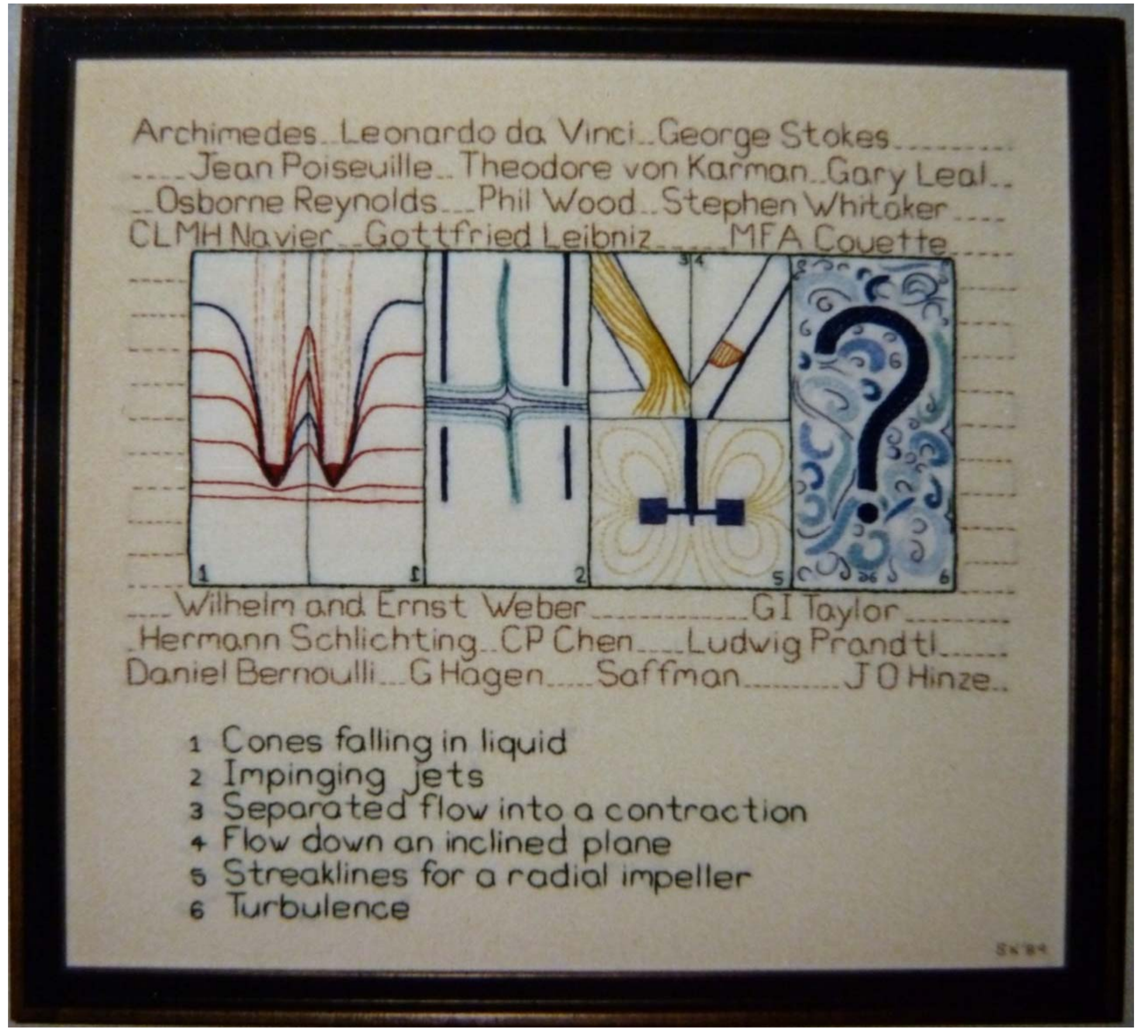
The power of "Why?"

Many new tools for guiding exploration

The Power of Why?

- In engineering, we tend to teach all about HOW to do it correctly and forget about WHY? we want to do it at all.
- Innovation is all about WHY?

- We can change this!
- It is more fun...



Mom, Age 24

Creative Problem Solving

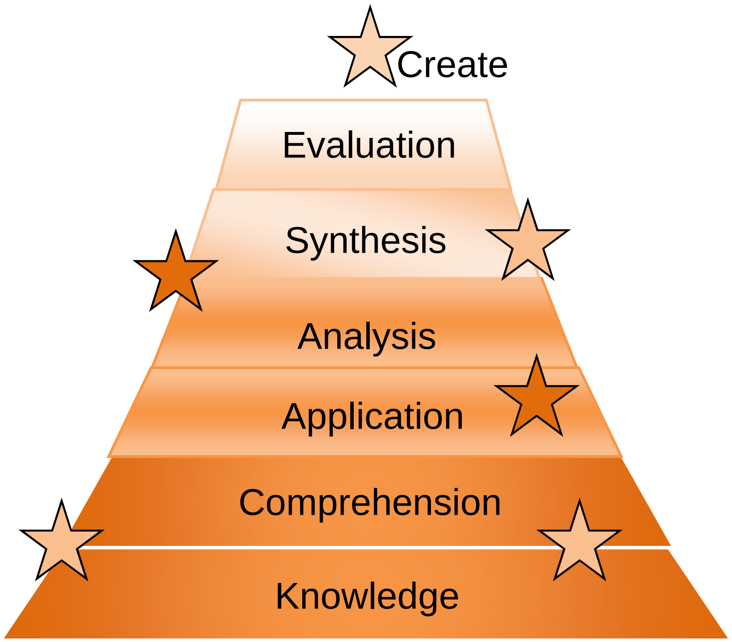
- Initial model (Woods) identified six stages: Engage, Define, Explore, Plan, Do it, and Look Back.
- Of these stages, four are reframed as the *creative* problem solving process: Clarify (define+), Ideation (explore+), Develop (plan+), and Implement (do it+)
- This is a critical shift for us in teaching engineering, because it identifies places in the teaching process where we tend to miss an opening for *divergent* thinking and *expansion* of perspective.

Examples of divergent thinking that can be applied in any core course:

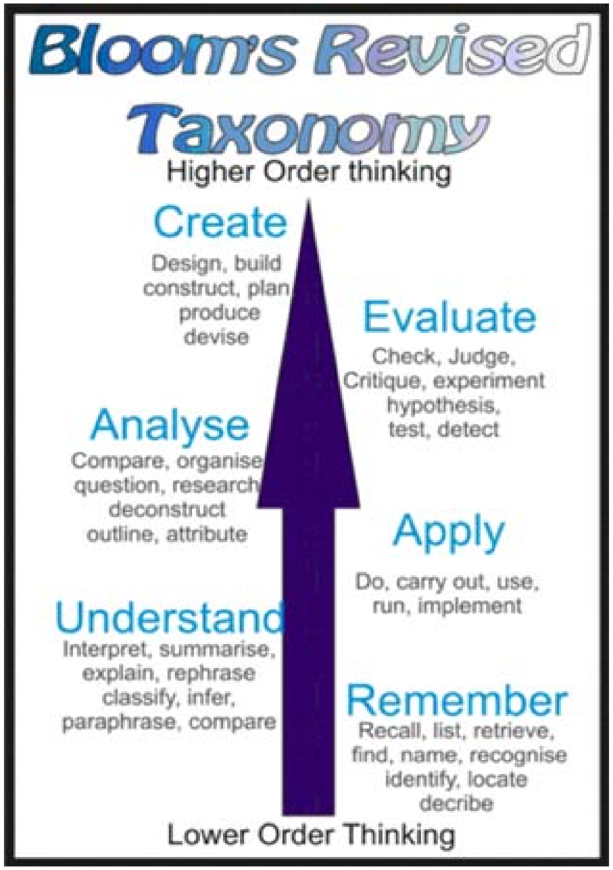
- Clarify and Define: WHY is this equipment needed? WHAT ROLE does it play in the process? Is this a NECESSARY step? Is there a DIFFERENT way to achieve the same goal? Do we have the CORRECT OBJECTIVE?
- Ideation and Development: Many good tools and illustrations in several references at the end of the talk.
- Implementation (Do it): This is a really key step because it allows us to move out of the simple linear problem solving to a more iterative and realistic framework. Am I solving this in the BEST way? What am I trying to LEARN from this solution? Where are the weaknesses in my ASSUMPTIONS? Do I need more INFORMATION to get the result I need?

Checking Bloom's Taxonomy

These questions move education up the ladder. Value added.



Synthesis: Combine or rearrange elements to propose alternative solutions or solve a new problem



Process Analysis: Data Forensics

- A stream is ambiguously labeled (thus illustrating the importance of material balance tables and stream numbers).
  - Where does the composition belong?
  - Is the problem fully specified?
  - Does the data conflict or agree?
  - Which solution makes more sense?

❖ This is a realistic data forensics situation that many of them will meet in industry. It forces them to try many solutions and critically analyse the results to find the best solution – and points out other weaknesses in the process along the way!

❖ Students are exposed to resilience, divergent problem solving, and critical thinking.

What's in the Box?

- A series of classroom demonstrations in MatE at the UofA that the STUDENTS do in class
  - raise a question or conflict with their intuition
  - try a series of tests to explore the reality
  - apply theory to explain what they find
  - variation applied in ungraded exploration lab in mixing
- Some interesting points
  - the more guided the exploration, the less creative the inquiry
  - unguided discovery learning is very hard to undo – so you want them to get the right message!

Troubleshooting: Robust Design

- Teaching robust design is nearly impossible.
- The upside-down problem is wonderful
  - provide students with a process that does not work
  - assign them (in teams) the job of uncovering the problem and proposing <u>solutions (plural).</u>
- They learn to critically evaluate a P&ID, to identify problems in the logic, and to apply divergent thinking to improve the robustness of the process
- They also learn the importance of getting feedback from an arm's length perspective!

Why else?

"Higher order questions lead to more engaged and curious learners, but ultimately, we shouldn't do this just because it will improve career prospects and improve the economy. *We should do it because it will improve their lives.* Curiosity drives people to *"challenge their views of self, others, and the world with an inevitable stretching of information, knowledge, and skills. They are more likely to approach, not avoid, novel, uncertain and complex activities and be happier."*

Amanda Lang, The Power of Why?, pg 35

5. Being Values Driven and Strategic

Now that we have more information, let's go back and check some of our basic assumptions.

We SAY we want innovation...

- Teaching innovation does not scale. You need mentors and iconoclastic instructors. You need small groups and mentoring. Co-op and industrially mentored design projects (Univ. Alberta) are critical to success. We will need more, not less.
- Canadian society is content and placid, not restless.
- Our culture's role models are parents and entertainers, not engineers – but that can change if we learn to tell our stories!
- Innovation is disruptive and harder to manage.

http://www.forbes.com/2009/08/27/dean-kamen-education-thought-leaders-innovation.html

Being an Innovator

Innovators can look like disrupters, rebels, or whistleblowers, and we owe it to our students to equip them with communication skills to match the technical skills if we want to move in this direction. *See EWB's excellent training programs.*

Leadership has to remain open to novelty despite high-pressured environments that are often geared more toward "making it through the day" and "deliverables" than producing well-developed and novel products, improvements, processes, or new directions. (Grivas)

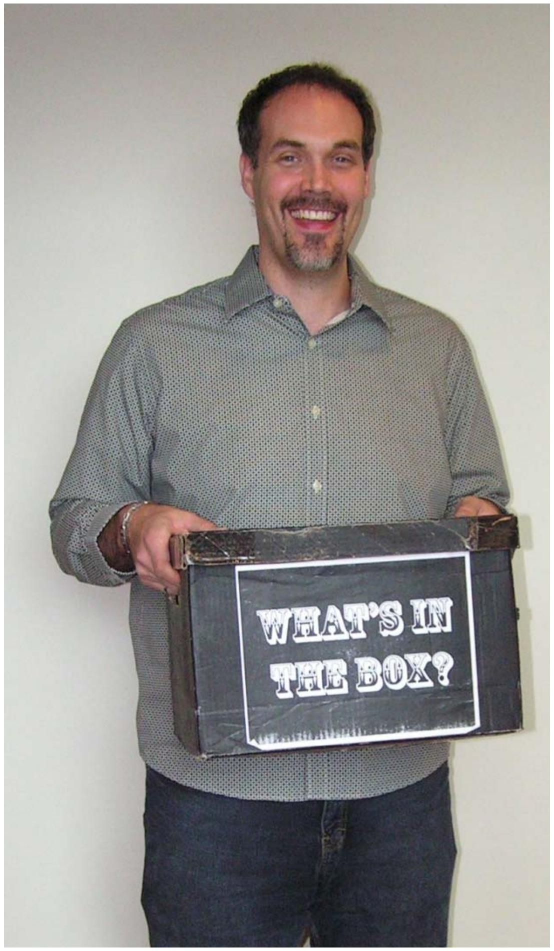
Innovation requires an environment of trust, engagement, and openness.

Some Words of Wisdom

- Transforming learners is not an easy place to stand.
- Do not think so much about yourself and how you are coming across, but about the students and what they need.
- Never lose sight of the fact that you are the servant and the viewers are the masters, BUT ALWAYS remain in control and convey competence.
- They need a piece of you in order to feel connected and cared for, but you can pick which piece you are able to share.

One last thought.

- Over the last 100 years, the locus of the economy has transitioned from agriculture, to manufacturing, to service. Consumer spending is now 70% of the economy – people spending money they do not have to buy things they do not need while using up non-renewable resources.
- What if we need a new economy and a new set of values that invests in solving the problems of the planet in innovative and meaningful ways?
- What if money is not the best value proposition to move us forward into the next century? What if money is a tool for change rather than a goal in and of itself?



The day will come when after harnessing the winds, the tides, and the forces of gravity, we shall harness for God the energies of love. And on that day for the second time in the history of the world, man will have discovered fire.

Pierre Teilhard de Chardin (1 May 1881 – 10 April 1955)
priest, paleontologist, and philosopher

Please Play!

Reading List (in order of usefulness)

1. The Power of Why, Amanda Lang, 2012. *Teaching curiosity. Many good teaching ideas.*
2. What the Best College Teachers Do, Ken Bain, 2004. *Building mastery and excellence. Inspiring meta-study of 100 excellent professors.*
3. Creating Innovators, Tony Wagner, 2012. *Technical and social innovators and what made them.*
4. The Innovative Team, Grivas and Puccio, 2012. *The creative problem solving steps in action, with an overlay of divergent and convergent thinking. Many good facilitation tools.*
5. Rolf Smith, 7 Levels of Change - Third Edition: Different Thinking for Different Results. *The design process is not so much a eureka moment as a series of idea tumblers.*
6. Good Business, Leadership, Flow, and the Making of Meaning, Mihaly Csikszentmihalyi, 1990. *Getting to mastery. Several related titles, including his famous book* Flow.
7. Switch, How to Change Things When Change is Hard, Heath and Heath, 2010. *Communication tools to shift perception and paradigms.*
8. The Art of Possibility, Zander and Zander, 2000. *Strategic thinking. Excellent teaching.*
9. Great by Choice, Jim Collins and Morten Hansen, 2011. *Strategic implementation.*

10. *Independent Project Analysis* (www.ipaglobal.com) IPA has studied thousands of projects, and has identified formal procedures which add significant value to projects.
11. *Conference Board of Canada Council on Innovation and Commercialization, http://www.conferenceboard.ca/networks/cic/default.aspx*