The Future Forms of STEM Education

Note: This version has slides with supplementary information, and additional slides that were not all shown on the day.

These cover notes material that was discussed but not visible in the original display. Including this as text here is intended to make the overall narrative more accessible, and to provide additional references.

Peter Maclaren

Centre for Learning and Teaching

AUT

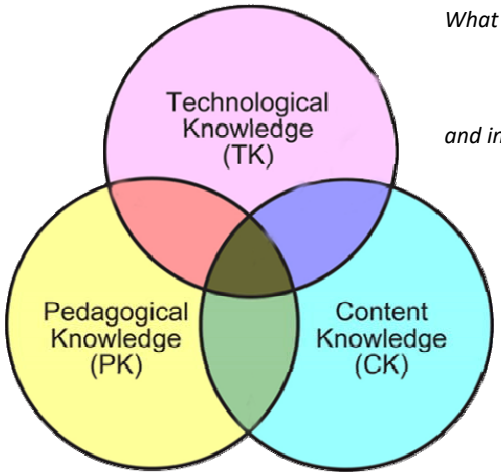
What does the future look like?

The future is already here

It's just not evenly distributed yet

attributed to William Gibson
author of Neuromancer (1984)

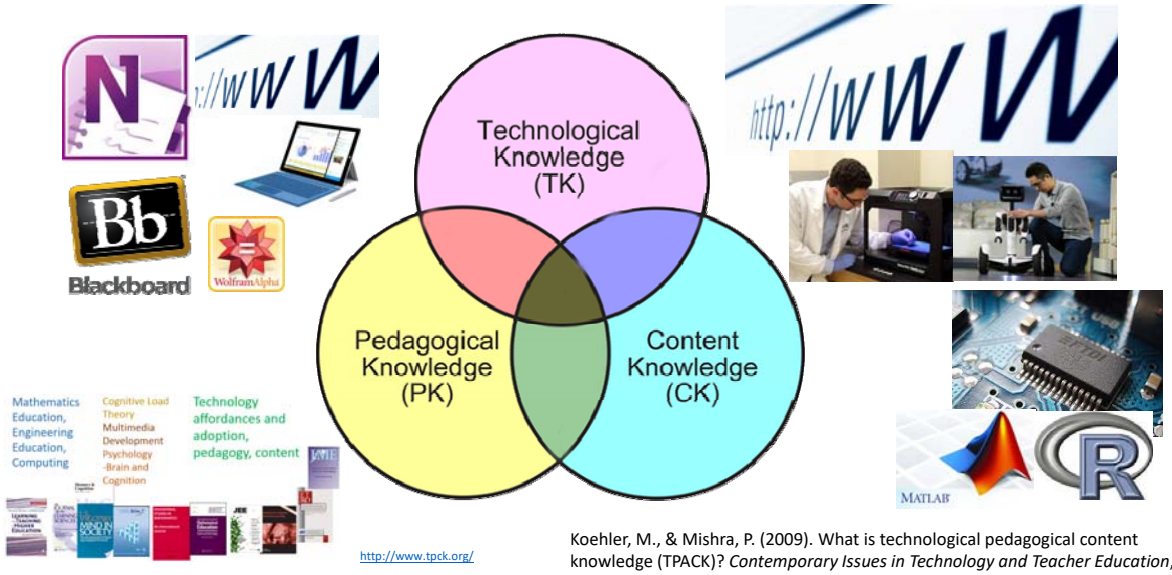
TPACK - Technology <-> Pedagogy <-> Content



What has changed/is new in knowledge of:
Technology
Pedagogy
Content (STEM discipline)
and in the intersection of these areas?

Koehler, M., & Mishra, P. (2009). What is technological pedagogical content knowledge (TPACK)? *Contemporary Issues in Technology and Teacher Education*, *9*(1), 60–70. http://www.tpck.org/

TPACK - Technology <-> Pedagogy <-> Content



http://www.tpck.org/

Koehler, M., & Mishra, P. (2009). What is technological pedagogical content knowledge (TPACK)? *Contemporary Issues in Technology and Teacher Education*, *9*(1), 60–70.

Reaching Students

What Research Says About Effective Instruction in Undergraduate Science and Engineering

The National Academies of SCIENCES ENGINEERING MEDICINE

Kober, N. (2015). Reaching Students: What Research Says About Effective Instruction in Undergraduate Science and Engineering. National Academies Press.

Reaching Students

What Research Says About Effective Instruction in Undergraduate Science and Engineering

Evidence from research on learning and teaching in science and engineering suggests that a large part of the problem lies in the way these courses are traditionally taught

—through lectures and reading assignments, note-taking and memorization, and laboratories with specific instructions and a predetermined result.

Kober, N. (2015). Reaching Students: What Research Says About Effective Instruction in Undergraduate Science and Engineering. National Academies Press.

Lectures

.. in undergraduate STEM education, we have the curious situation that, although more effective teaching methods have been overwhelmingly demonstrated, most STEM courses are still taught by lectures

— the pedagogical equivalent of bloodletting

Wieman, C. E. (2014). Large-scale comparison of science teaching methods sends clear message. Proceedings of the National Academy of Sciences, 111(23), 8319–8320. http://doi.org/10.1073/pnas.1407304111

Lectures

The most fundamental problem of lectures is that they tend to be based on the information transmission fallacy.

This is the idea that what is taught by the teacher is remembered by the student.
In reality however, students do not store information as taught.

Schmidt, H. G., Wagener, S. L., Smeets, G. A. C. M., Keemink, L. M., & van der Molen, H. T. (2015). On the Use and Misuse of Lectures in Higher Education. Health Professions Education, 1(1), 12–18. https://doi.org/10.1016/j.hpe.2015.11.010

Lectures and Notetaking

Typically fewer than 40% of the important lecture ideas are recorded.

Titsworth, B. S., & Kiewra, K. A. (2004). Spoken organizational lecture cues and student notetaking as facilitators of student learning. Contemporary Educational Psychology, 29(4), 447–461. http://doi.org/10.1016/j.cedpsych.2003.12.001

Blended Learning - meta-analysis of research

Blended Learning outperforms fully face-to-face classroom instruction*.

Means, B., Toyama, Y., Murphy, R., & Baki, M. (2013). The effectiveness of online and blended learning: A meta-analysis of the empirical literature. *Teachers College Record*, *115*(3), 1–47.

*Conditions apply

Blended Learning - student satisfaction

Student satisfaction is greater in blended courses.*

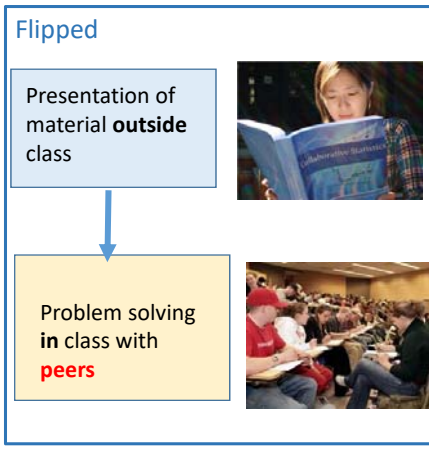
Martínez-Caro, E., & Campuzano-Bolarín, F. (2011). Factors affecting students' satisfaction in engineering disciplines: traditional vs. blended approaches. *European Journal of Engineering Education*, *36*(5), 473–483. http://doi.org/10.1080/03043797.2011.619647

*Conditions apply

The Flipped Classroom – Peer Instruction

Eric Mazur

https://youtu.be/FUY049rIjdM

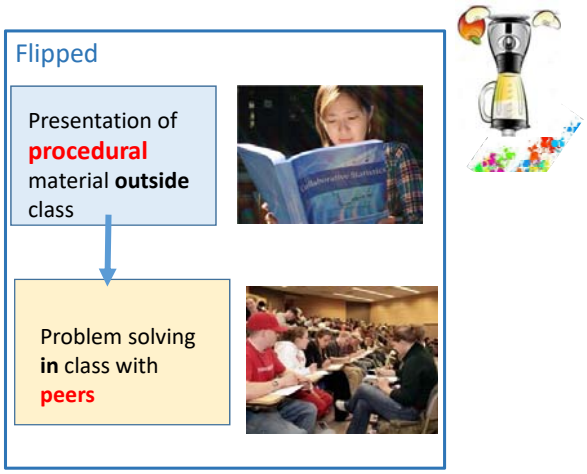


Crouch, C. H., & Mazur, E. (2001). Peer Instruction: Ten years of experience and results. *American Journal of Physics*, *69*(9)

Fagen, A. P., Crouch, C. H., & Mazur, E. (2002). Peer instruction: Results from a range of classrooms. *Physics Teacher*, *40*(4)

The Flipped Classroom – Peer Instruction

.. overwhelmingly improves students' problem solving abilities*

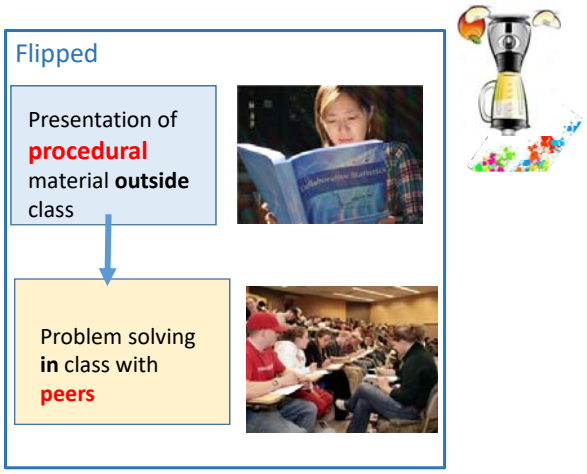


Vickrey, T., Rosploch, K., Rahmanian, R., Pilarz, M., & Stains, M. (2015). Research-Based Implementation of Peer Instruction: A Literature Review. *CBE-Life Sciences Education*, *14*(1), es3.

*Conditions apply

The Flipped Classroom

.. exam performance significantly improved *



Gross, David, Evava S. Pietri, Gordon Anderson, Karin Moyano-Camihort, and Mark J. Graham. "Increased Preclass Preparation Underlies Student Outcome Improvement in the Flipped Classroom." *CBE-Life Sciences Education* 14, no. 4 (December 21, 2015

*Conditions apply

Large-Enrollment Physics Class

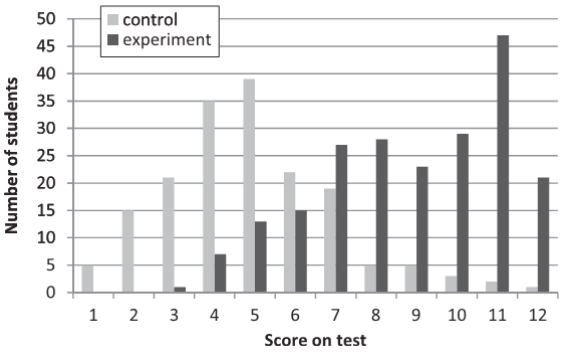
Control group

– experienced lecturer.

Experimental group

- postdoctoral fellow

- *increased student attendance,*
- *higher engagement,*
- *and more than twice the learning**



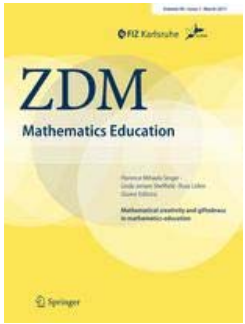
Deslauriers, L., Schelew, E., & Wieman, C. (2011). Improved Learning in a Large-Enrollment Physics Class. SCIENCE, 332(6031), 862–864.

Teaching methods comparison in a large calculus class

.. we report improved student performance

— on conceptual items in particular

— with a switching replication in that each section outperformed the other on the topic for which it received the intervention



Code, Warren, Costanza Piccolo, David Kohler, and Mark MacLean. "Teaching Methods Comparison in a Large Calculus Class." *ZDM* 46, no. 4 (August 2014): 589–601. doi:10.1007/s11858-014-0582-2.

Hawthorne Effect?

Journal of University Teaching & Learning Practice

Volume 11 | Issue 1 Article 6

2014

Using Innovative Tools to Teach Computer Application to Business Students - A Hawthorne Effect or Successful Implementation Here to Stay

Khan, Zeenath Reza. "Using Innovative Tools to Teach Computer Application to Business Students–A Hawthorne Effect or Successful Implementation Here to Stay." *Journal of University Teaching and Learning Practice* 11, no. 1 (2014): 6.

Lectures and Notetaking

.. the lecture theater is a good place to tell stories.

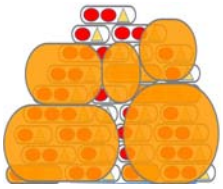
Finally, lectures have survived as a cost-effective way to instruct large numbers of students.

Schmidt, H. G., Wagener, S. L., Smeets, G. A. C. M., Keemink, L. M., & van der Molen, H. T. (2015). On the Use and Misuse of Lectures in Higher Education. Health Professions Education, 1(1), 12–18. https://doi.org/10.1016/j.hpe.2015.11.010

Types of Discipline Knowledge

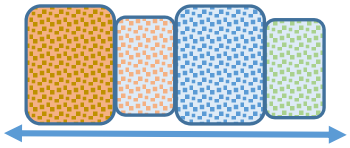
Vertical Knowledge Structures (Hierarchical)

Integration
Subsumption



Horizontal Knowledge Structures

Accumulation
Segmentation



Images: ©Peter Maclaren

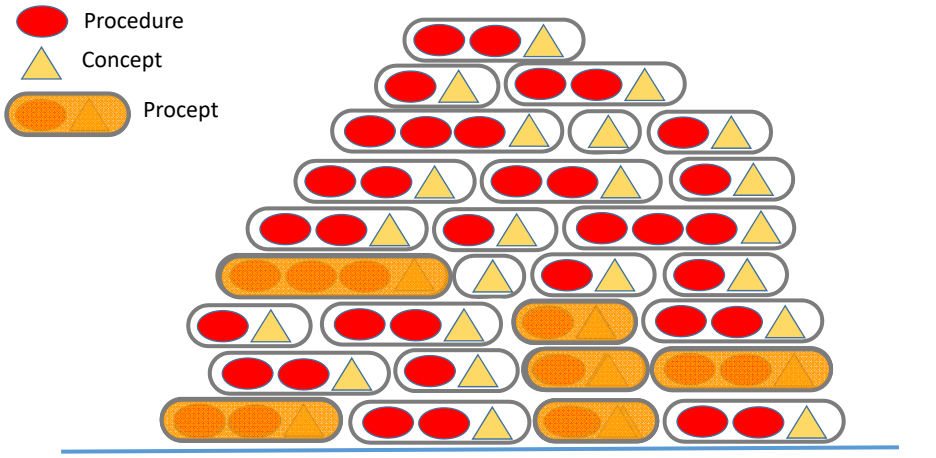
Maton, Karl. (2009) Cumulative and Segmented Learning: Exploring the Role of Curriculum Structures in Knowledge-building. *British Journal of Sociology of Education* 30, no. 1

Bloom's (Revised) Taxonomy

Cognitive Domain	Knowledge Dimension			
Cognitive Process Dimension	Factual	Procedural	Conceptual	Metacognitive
Create				
Evaluate				
Analyse				
Apply				
Understand				
Remember				

Krathwohl, David R. "A Revision of Bloom's Taxonomy: An Overview." *Theory Into Practice* 41, no. 4 (2002)

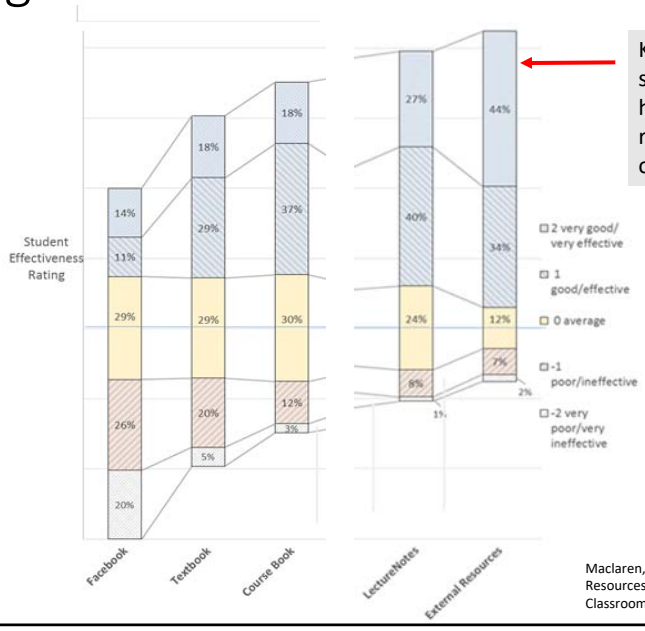
Procedural and Conceptual Thinking in STEM



Images: ©Peter Maclaren

Tall, David. "The Theory Of Procepts." *Mathematics Teaching*, 1992, 2–7.

Engineering Maths 1 and 2



Khan Academy and similar sites – highest rated resource for study outside class.

Maclaren, Peter. "How Do You Do That? Student Views on Resources Used Outside the Engineering Mathematics Classroom." *In Development*, 2017.

A Conceptual Problem

2 people are in a canoe which is sitting in a swimming pool. They take a cannonball which is in the canoe and drop it into the pool.

Does the water level in the swimming pool:

a) go up

b) go down

c) stay the same?

Adapted from: Schwartz, Marc. "Khan Academy: The Illusion of Understanding." *Online Learning* 17, no. 4 (2013). https://olj.onlinelearningconsortium.org/index.php/olj/article/view/364.

Procedural Knowledge (Instrumental Understanding)

Instrumental understanding in a mathematical situation consists of recognizing a task as one of a particular class for which one already knows a rule.

Skemp, Richard R. *Intelligence, Learning, and Action: A Foundation for Theory and Practice in Education*. Wiley, 1979.

Engineering Maths I

Questions:

1. [15 marks] Find the derivative $\frac{dy}{dx}$ for each of the following:

   (a) $y = e^{1-\cos 2x}$

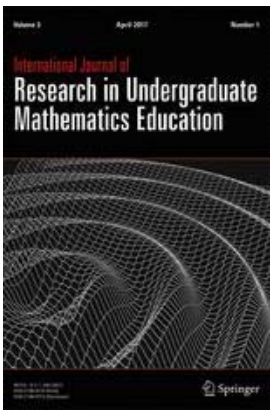
   (b) $y = x^{x^2}$ [Hint: Use logarithmic differentiation]

   (c) $2x^2y + 3xy^2 = 16$ [Hint: Use implicit differentiation]

A Characterization of Calculus I Final Exams (US Universities)

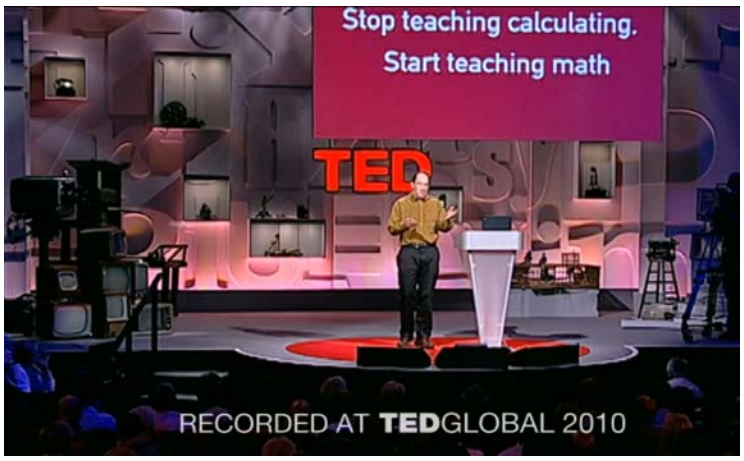
– focus on procedural fluency

the exams generally require low levels of cognitive demand, seldom contain problems stated in a real-world context, rarely elicit explanation, and do not require students to demonstrate or apply their understanding of the course's central ideas.



Tallman, Michael A., Marilyn P. Carlson, David M. Bressoud, and Michael Pearson. "A Characterization of Calculus I Final Exams in U.S. Colleges and Universities." *International Journal of Research in Undergraduate Mathematics Education* 2, no. 1 (April 2016): 105–33. doi:10.1007/s40753-015-0023-9.

Mathematics and Computers



Conrad Wolfram Ted Global 2010

http://www.ted.com/talks/conrad_wolfram_teaching_kids_real_math_with_computers?language=en#t-8582

Mathematics and Computers

Use computers for...

1. Posing the right questions
2. Real world ⟶ math formulation
3. **Computation**
4. Math formulation ⟶ real world, verification

Conrad Wolfram Ted Global 2010

http://www.ted.com/talks/conrad_wolfram_teaching_kids_real_math_with_computers?language=en#t-8582

Mathematics and Computers

Use students for...

1. Posing the right questions
2. Real world ⟶ math formulation
3. Computation
4. Math formulation ⟶ real world, verification

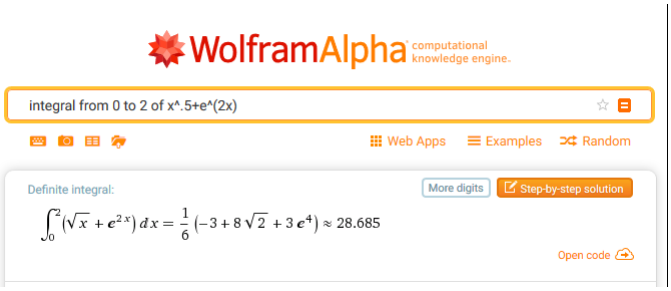
Conrad Wolfram Ted Global 2010

http://www.ted.com/talks/conrad_wolfram_teaching_kids_real_math_with_computers?language=en#t-8582

Engineering Maths I

3. [15 marks] Evaluate the following integrals

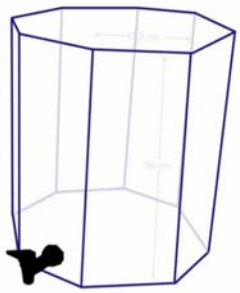
(a) $\int_0^2 \left(\sqrt{x} + e^{2x}\right)\, dx$



Mathematics Education

11. A water tank is in the form of a regular octagonal prism. The base octagon has side length 11.9 cm. The lateral edge of the water tank is 36 cm.

a) What is the surface area of the base?
b) What is the volume of the water tank?
c) If you pour water into the tank at a rate of 1.8 oz./sec., how long will it take you to fill the tank?



A 'maths textbook' problem – just find equations to fit and do the procedural calculations

Dan Meyer TEDxNYED 2010

http://www.ted.com/talks/dan_meyer_math_curriculum_makeover

Mathematics Education

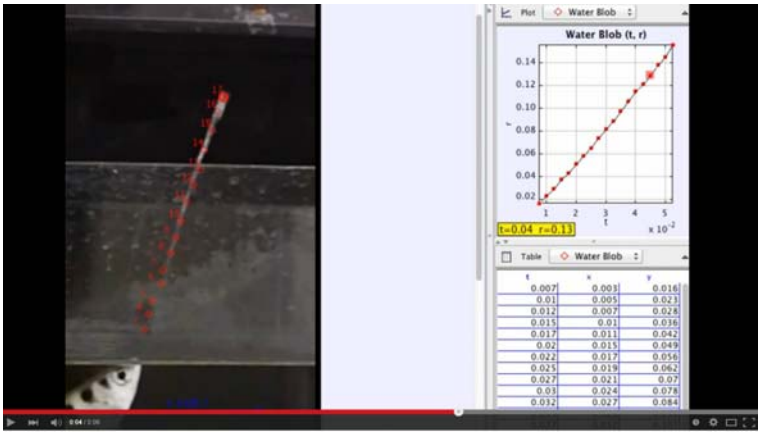
Real life exploration

Dan Meyer TEDxNYED 2010

http://www.ted.com/talks/dan_meyer_math_curriculum_makeover

Engineering Mathematics Education

Modelling using Tracker software



Archerfish

https://www.youtube.com/watch?v=Q

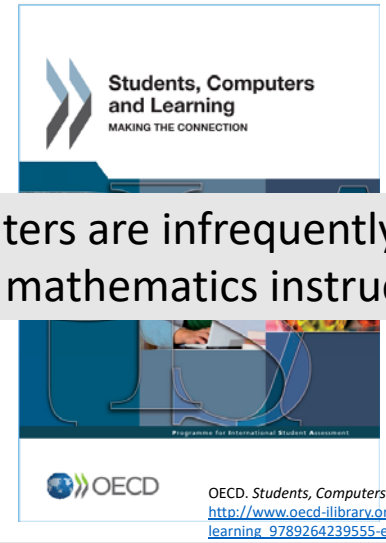
BYOD and Blended Classrooms

.. BYOD (Bring Your Own Device) and blended classrooms are beginning to become the norm in New Zealand schools.

NZQA 2013

http://www.nzqa.govt.nz/assets/About-us/News/SPANZ-presentation-Future-State-26-March-2013.pdf

Technology Use – OECD Report



computers are infrequently used during mathematics instruction.

OECD. *Students, Computers and Learning*. PISA. OECD Publishing, 2015. http://www.oecd-ilibrary.org/education/students-computers-and-learning_9789264239555-en .

Scientific Thinking and Representation

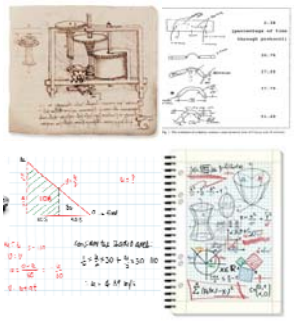
Thinking in mathematics is inextricably interwoven with *writing* mathematics

Greiffenhagen, C. **The materiality of mathematics: presenting mathematics at the blackboard**. British Journal of Sociology

The cinematic art of teaching university mathematics: chalk talk as embodied practice
Fox, J & Artemeva, N
from: Multimodal Communication 1(1), pp. 83-103 December 2011

Scientific Thinking and Representation

visual, spatial, and mathematical representations are essential tools for communicating and remembering ideas and solving problems.



Kober, N (2015). Reaching Students: What Research Says About Effective Instruction in Undergraduate Science and Engineering. National Academies Press.

Writing Sketching Thinking Communicating

Writing Sketching Thinking Communicating

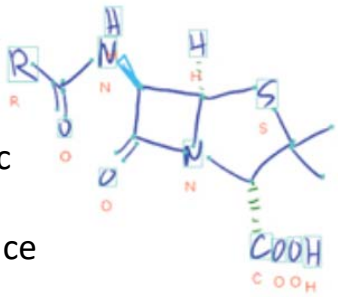
in a digital environment?

Writing Sketching Thinking Communicating

in a digital environment?

Scientific Thinking and Representation

.. a pen interface stimulates people to write more nonlinguistic content (diagrams, symbols), compared with a keyboard interface or a non-digital pen.



Oviatt, Sharon, Adrienne Cohen, Andrea Miller, Kumi Hodge, and Ariana Mann. "The Impact of Interface Affordances on Human Ideation, Problem Solving, and Inferential Reasoning." *ACM Transactions on Computer-Human Interaction* 19, no. 3

Pen-Enabled Tablet PC Environment

The Flipped Classroom

Traditional

Presentation of content material **in** class

Problem solving **outside** class - **homework**

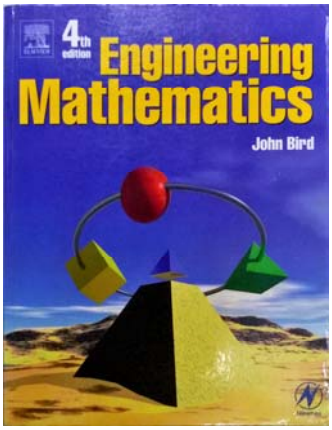
Flipped

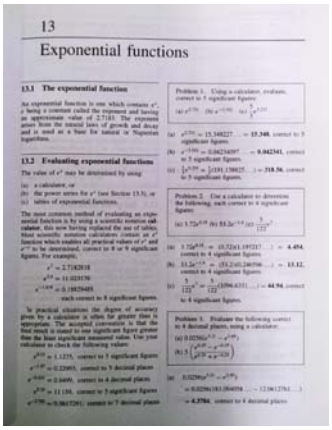
Presentation of material **outside** class

Problem solving **in** class with **peers**

https://youtu.be/FUY049rIjdM

Why not just read a text book?



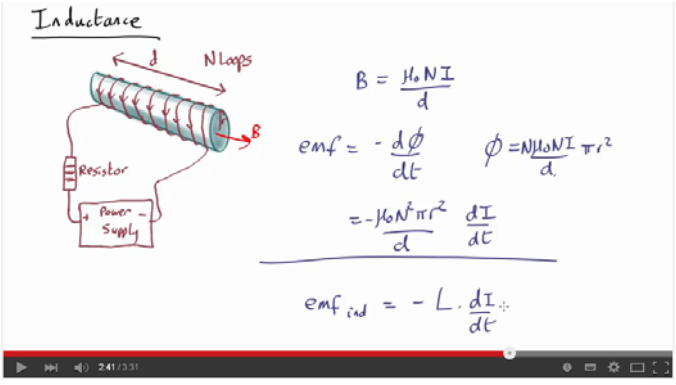

13
Exponential functions

Lacks dynamic procedural development

Worked Examples and Screencasts

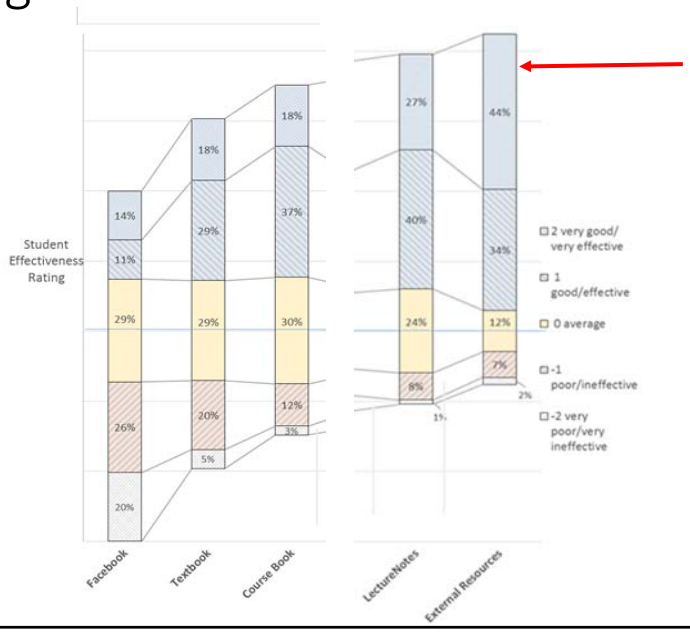
EXAMPLECASTS: THE UNREASONABLE EFFECTIVENESS OF WEBCAST WORKED EXAMPLES IN INTRODUCTORY UNIVERSITY PHYSICS

Paul Francis[a,b]



Francis, Paul J. "Examplecasts: The Unreasonable Effectiveness of Webcast Worked Examples in Introductory University Physics." In *Proceedings of The Australian Conference on Science and Mathematics Education (formerly UniServe Science Conference)*, 2013.

Engineering Maths 1 and 2



Khan Academy (& similar external resources) the highest rated resource by AUT Eng Maths Students

Change

Barriers to Change

… lectures have survived as a cost-effective way to instruct large numbers of students.

Schmidt, H. G., Wagener, S. L., Smeets, G. A. C. M., Keemink, L. M., & van der Molen, H. T. (2015). On the Use and Misuse of Lectures in Higher Education. Health Professions Education, 1(1), 12–18. https://doi.org/10.1016/j.hpe.2015.11.010

Barriers to Change

Your views???

Barriers to Change

expectations of content coverage, limited instructor time for multiple responsibilities, lack of training and curriculum materials, departmental norms, student resistance, class size and room layout, time structure, fiscal resources, appropriate facilities, and institutional reward structures and culture, particularly research priorities

Besterfield-Sacre, Mary, Monica F. Cox, Maura Borrego, Kacey Beddoes, and Jiabin Zhu. "Changing Engineering Education: Views of U.S. Faculty, Chairs, and Deans: Survey of Views on Changing Engineering Education." *Journal of Engineering Education* 103, no. 2 (April 2014): 193–219. doi:10.1002/jee.20043.

Barriers to Change

More specifically, by tending to favor research over teaching, systems and reward structures promote the status quo in teaching and curriculum.

Besterfield-Sacre, Mary, Monica F. Cox, Maura Borrego, Kacey Beddoes, and Jiabin Zhu. "Changing Engineering Education: Views of U.S. Faculty, Chairs, and Deans: Survey of Views on Changing Engineering Education." *Journal of Engineering Education* 103, no. 2 (April 2014): 193–219. doi:10.1002/jee.20043.

Recommendations for Change

For example, deans and departments should:

- *Find ways to diffuse innovations to faculty members in other departments who teach engineering students. (Lattuca, 2011; Merton et al., 2001)*
- *Provide opportunities for graduate students to learn about innovative teaching methods (supervised and mentored teaching and reflection opportunities) and hire graduates with a record Of interest in teaching and curriculum development. (Lattuca, 2011; Lattuca & Stark, 2009)*
- *Provide professional development opportunities for faculty to learn about teaching, curriculum design, and student learning by means of teaching and learning centers and workshops (Lattuca & Stark, 2009) and continuous discussion, evaluation, and assessment of curricula, teaching, and learning. (Lattuca & Stark, 2009; Merton et al., 2001)*
- *Reward faculty who have made improvements in teaching and learning and remove disincentives for trying; establish official criteria that value and reward teaching, both monetarily and in tenure and promotion. (Lattuci & Stark, 2009; Merton et al., 2001)*
- *Create new structures, positions, and policies to accommodate innovations. (Lattuca & stark, 2009)*
- *Give faculty extra time such as release time or extensions on the tenure and promotion period to try new methods. (Seymour et al., 2011)*
- *Engage senior colleagues with power and influence in the change process. (Mertonet al., 2001; Seymour et al., 2011)*
- *Offer faculty easily accessible and useful resources for implementing teaching innovations. (Lattuca & Stark, 2009; Seymour et al., 2011)*

Besterfield-Sacre, Mary, Monica F. Cox, Maura Borrego, Kacey Beddoes, and Jiabin Zhu. "Changing Engineering Education: Views of U.S. Faculty, Chairs, and Deans: Survey of Views on Changing Engineering Education." *Journal of Engineering Education* 103, no. 2 (April 2014): 193–219. doi:10.1002/jee.20043.

Barriers to Change

"Culture eats strategy for breakfast."

(attributed to) Peter Drucker

Lukasz Kawilski, CIO of the New Zealand Qualifications Authority (NZQA).

http://www.cio.co.nz/article/609005/lukasz-zawilski-dawn-digital-nz-qualifications-authority/

Radical innovation and the challenge of socio-technical transitions

Slayton, Rebecca, and Graham Spinardi. "Radical Innovation in Scaling up: Boeing's Dreamliner and the Challenge of Socio-Technical Transitions." *Technovation* 47 (January 2016): 47–58. doi:10.1016/j.technovation.2015.08.004 .

Lecture-Based vs Challenge-Based Learning at Boeing

Challenge based learning showed:

- More interaction and sharing of knowledge
- Better integration and synthesis of concepts

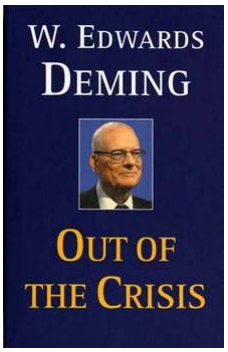
O'Mahony, Timothy K., Nancy J. Vye, John D. Bransford, Elizabeth A. Sanders, Reed Stevens, Richard D. Stephens, Michael C. Richey, Kuen Y. Lin, and Moe K. Soleiman. "A Comparison of Lecture-Based and Challenge-Based Learning in a Workplace Setting: Course Designs, Patterns of Interactivity, and Learning Outcomes." *Journal of the Learning Sciences* 21, no. 1 (January 2012): 182–206. doi:10.1080/10508406.2011.611775.

Change

System issues

account for most problems and possibilities for improvement.

W. Edwards Deming



Deming, W. Edwards. *Out of the Crisis*. MIT Press, 2000. https://mitpress.mit.edu/books/out-crisis.

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"The new building will include

……. collaborative
social learning spaces

"design … informed by thorough research into the campuses at future-focused universities like ***Queensland University of Technology and RMIT"*** *Academic development for learning spaces*

http://www.aut.ac.nz/study-at-aut/campuses/current-campus-updates

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"… will lead the way for greater collaboration and faster adoption of new technologies."

http://www.skyscrapercity.com/showthread.php?t=1902150>

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While universities are enthusiastic about building new student-centred and technology-enriched learning spaces, ***there is less emphasis on how teachers are helped to re-conceptualise their learning designs for these spaces.****."*

Steel, Caroline, and Trish Andrews. "Re-Imagining Teaching for Technology-Enriched Learning Spaces: An Academic Development Model." In *Physical and Virtual Learning Spaces in Higher Education: Concepts for the Modern Learning Environment*, 242–265. IGI Global, 2012. http://www.igi-global.com/chapter/imagining-teaching-technology-enriched-learning/56053.

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few have had the opportunity to re-conceptualise the teaching of their discipline within this environment.
It is imperative to provide both timely and targeted professional development and explore with academics how these environments can be used to capitalise on new pedagogies, digital technologies and sustainable learning designs.

Hurford, Jon. "Transforming Teaching Practice through Professional Learning for Next Generation Learning Spaces," 2014. http://mams.rmit.edu.au/750b2f9b9j4yz.pdf.

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RMIT University has made significant investments in next generation learning spaces in the past with over 90 new or refurbished spaces. However, the teaching and learning possibilities that Next Generation Learning Spaces promise have not, on the whole, been exploited. There are many reasons for this lack of take up. Many academics have not been introduced to the space, the technology that it offers, or its potential for different approaches to teaching and learning.

Hurford, Jon. "Transforming Teaching Practice through Professional Learning for Next Generation Learning Spaces," 2014. http://mams.rmit.edu.au/750b2f9b9j4yz.pdf.

What will the future of STEM Education look like?