Evaluating the Impact of the Puzzle-Based Learning Pedagogical Strategy in Tertiary STEM Subjects

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Mediterranean Sea
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MALTA
AZERBAIJAN
GEORGIA
ARMENIA
AZER.
Black Sea
Caspian Sea
70°
60°
50°
40°
5°
0°
5°
15°
25°
35°
45°

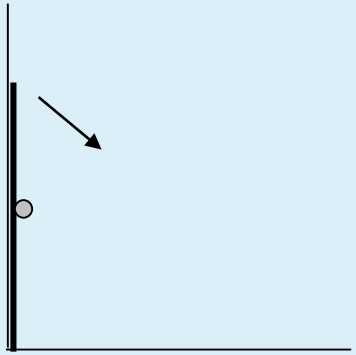
Puzzles

- A puzzle is a non-routine, non-standard problem presented in an entertaining way
- *Simplicity:* Easy to state and remember and looks deceptively simple
- *Surprise:* Teases by a surprising solution and an unexpected counterintuitive answer
- *Entertainment:* Fun to solve

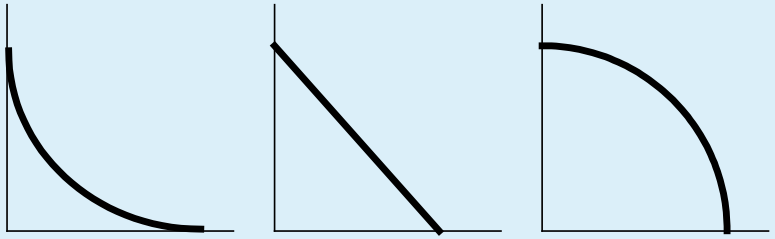
Edutainment = Education + Entertainment

Example 1: A Cat on a Ladder

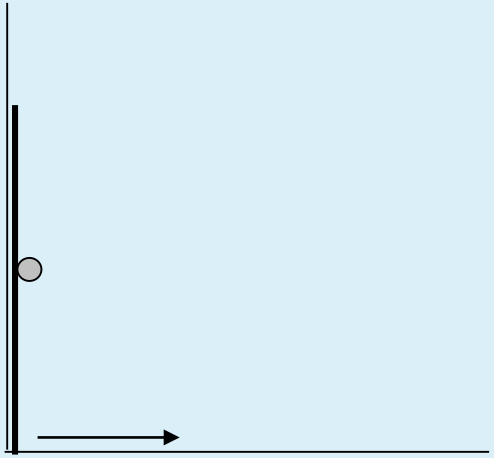
Imagine a cat sitting half way up a ladder that is placed almost flush with a wall.

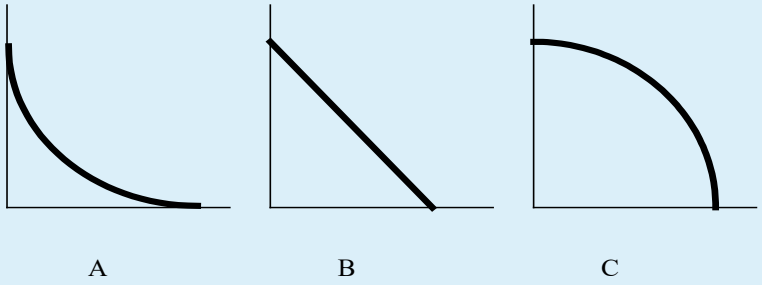


a) If the ladder falls what will the trajectory of the cat be? A, B or C?

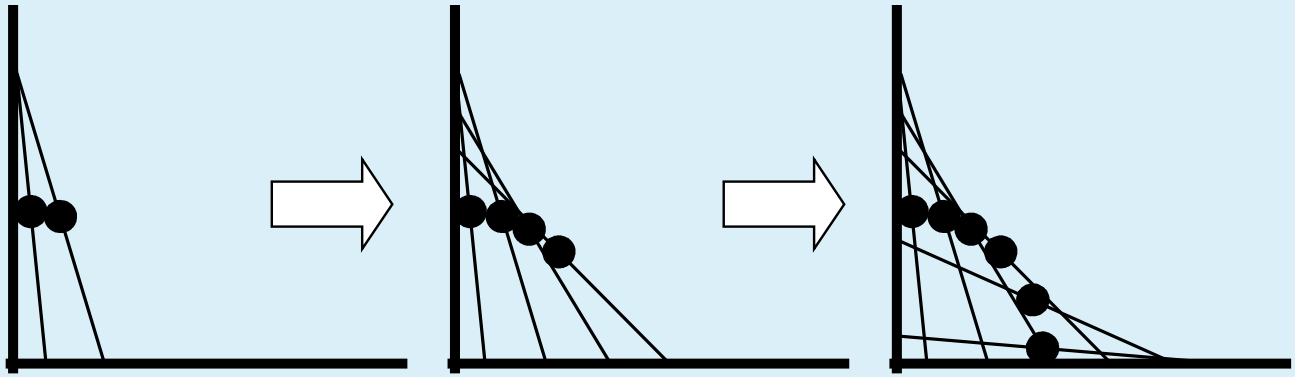


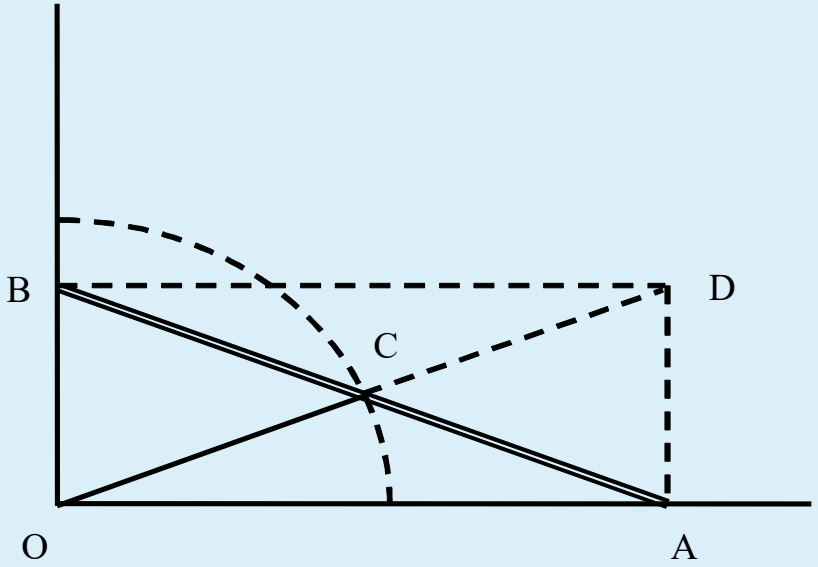
b) Now the *base* is pulled away with the top of the ladder retaining contact with the wall. What will the trajectory of the cat be? A, B or C?





Still C) !





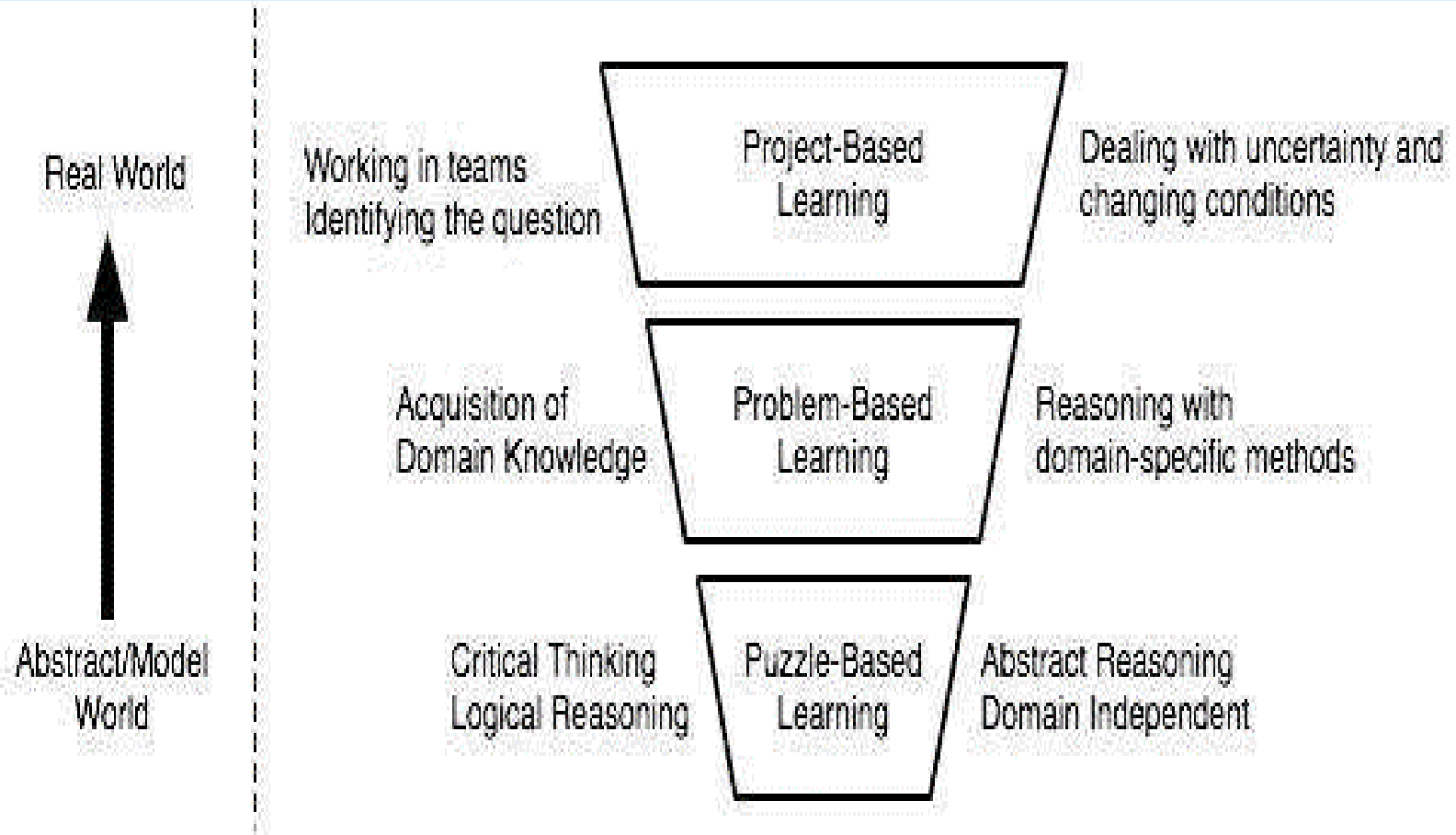
Example 2: A Chocolate Bar

A rectangular chocolate bar consists of 10 × 6 small rectangles and you wish to break it into its 60 constituent parts. At each step, you can only pick up one piece and break it along any of its vertical or horizontal lines. How should you break the chocolate bar using the *minimum* number of steps (breaks)? What is the *minimum* number?

Puzzle-Based Learning (PzBL)

- Developed by Z. Michalewicz (2008, 2014)
- Michalewicz, Z. & Michalewicz, M. (2008). *Puzzle-Based Learning: An introduction to critical thinking, mathematics, and problem solving*. Hybrid Publishers.
- Meyer, E.F., Falkner, N., Sooriamurthi, R., Michalewicz, Z. (2014). *Guide to Teaching Puzzle-Based Learning*. Springer.
- Criteria for a puzzle: independence (domain free); generality; simplicity; eureka factor; entertainment factor

Relationship between different PBL



Puzzle-Based Learning Courses

- PzBL concept/approach has a long history
- First maths puzzles in Sumerian texts - 2500 BC
- Alcuin, an English scholar born around 732 AD, “Problems to Sharpen the Young” 50 puzzles

- New: Developing PzBL ***academic*** courses for 1st year maths, computer science and engineering students – ***compulsory*** at some universities

Benefits for the Students - 1

1. **Generic:**

- Engage students' emotions, creativity and curiosity
- Enhance problem-solving, critical thinking and generic thinking skills
- Improve lateral thinking "outside the box"
- Increase motivation and the retention rate

Benefits for the Students - 2

2. Professional: illustrate many powerful problem solving principles such as:

- the invariance principle
- extreme principle
- induction principle
- pigeonhole (Dirichlet's box) principle
- start at the end
- guess and check
- famous Polya's problem solving techniques

Benefits for the Students - 3

3. Employability: practice for job interviews

Many companies use puzzles at their job interviews to evaluate candidate's problem solving skills and select the best from the best.

"Now more than ever, an education that emphasizes general problem solving skills will be important".

Bill Gates

Puzzles at Job Interviews

"The goal of Microsoft's interviews is to assess a general problem-solving ability rather than a specific competence. At Microsoft, and now at many other companies, it is believed that there are parallels between the reasoning used to solve puzzles and the thought processes involved in solving real problems of innovation. You have to hire for general problem-solving capacity."

Poundstone, W. (2004). *How would you move Mount Fuji?: Microsoft's Cult of the Puzzle -- How the World's Smartest Companies Select the Most Creative Thinkers.*

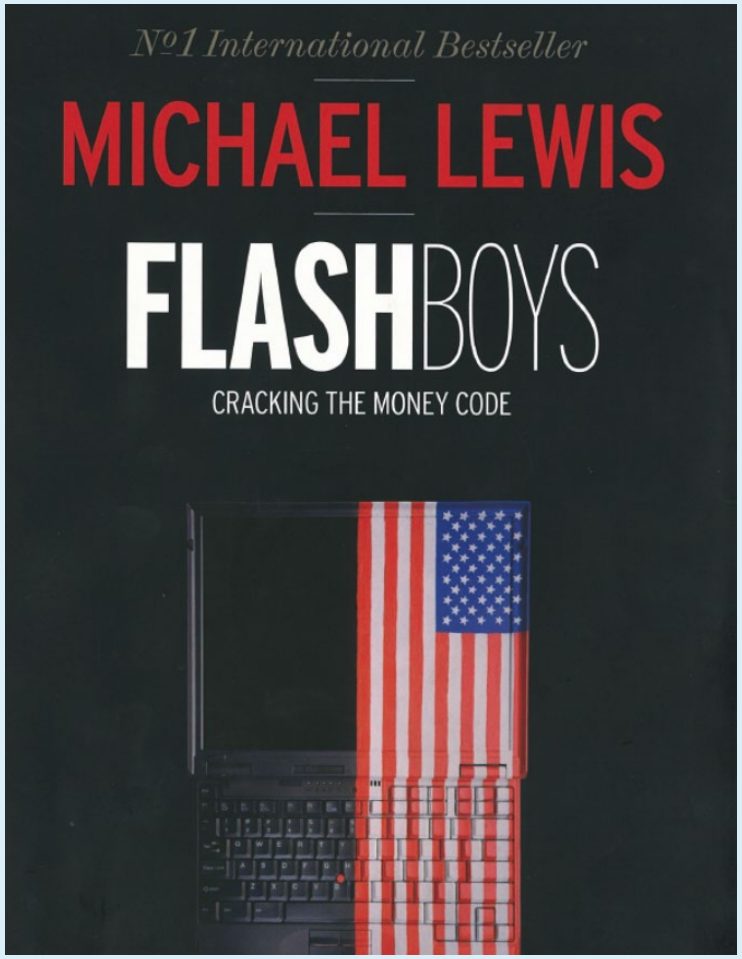
A View from New Zealand

- Many New Zealand innovative high-tech companies can't find suitable candidates in New Zealand and had to go through a long and expensive recruitment process hiring staff from overseas.
- There were many local applicants with suitable university degrees who could presumably do a routine job very well but the companies need more than that – they need candidates with highly innovative and creative thinking skills.
- **Creative and Innovative Thinking is a Workplace Requirement**

Real Examples

From the book "Flash Boys" by Michael Lewis, 2014

Hiring a programmer
for a financial company
on Wall Street, New York
with the annual salary
of 270,000 USD



Real Examples: Question 1

Question 1: Is 3599 a prime number?

This is where the boring formula from algebra

$$a^2 - b^2 = (a - b) \times (a + b)$$

can help you to become rich ☺

$$3599 = (3600 - 1) = (60^2 - 1^2) = (60 - 1)\,(60 + 1) = 59 \times 61$$

Real Examples: Question 2

sions. "He says there is a spider on the floor, and he gives me its coordinates. There is also a fly on the ceiling, and he gives me its coordinates as well. Then he asked the question: Calculate the shortest distance the spider can take to reach the fly." The spider can't fly or swing; it can only walk on surfaces. The

Real Examples: Question 2

shortest path between two points was a straight line, and so, Serge figured, it was a matter of unfolding the box, turning a three-dimensional object into a two-dimensional surface, then using the Pythagorean theorem to calculate the distances. This took him several minutes to work out; when he was done, Davidovich offered him a job at Goldman Sachs. His starting salary plus bonus came to $270,000.

Benefits for the Students - 4

4. Fun Short Breaks:

Question 3. Can you see any other benefits for you in solving the puzzles? What are they?

- It is a kind of fun break from the lecture which can help me concentrate; a break from the serious stuff;
- creating a fun learning environment;
- makes maths fun; allows a mini pause;
- it is a nice mental break during lectures;
- good way to escape doing triple integrals;
- helps relax mind to perform better.

Two Pilot Studies – 2015, 2016

- Second year engineering mathematics course
- 6 weeks: 2 puzzles a week during a break between 2 consecutive lectures
- Voluntary participation
- 2015: 62 responses out of 65 (response rate 95%)
- 2016: 93 responses out of 97 (response rate 96%)

Examples of the Puzzles Given to the Students

Puzzle 1: Average Speed

You drive a car at a constant speed of 40 km/h from **A** to **B**, and on arrival at **B** you return immediately to **A**, but at a higher speed of 60 km/h.

What was your average speed for the whole trip?

Puzzle 1: Average Speed

Average speed = Total distance / Total time

Try the distance between A and B as 120 km.

48 km/h

Puzzle 1: Average Speed

Suppose that you go from **A** to **B** at a constant speed of 40 km/h. What should your constant speed be for the return trip from **B** to **A** if you want to obtain the average speed of 80 km/h for the whole trip?

Puzzle 1: Average Speed

It is impossible! Even if you drive back from B to A at the speed of light your average speed for the whole trip still would be less than 80 km/h.

Consider the distance between A and B as 40 km.

Average speed = Total distance / Total time

Average speed of 80 km/h = 80 km / (1 h + … h)

Puzzle 2

Thirty two players take part in an individual tennis competition. What is the overall number of games, if a player who loses a game leaves the competition?

Research Questions

- What are students' perceptions on improving their problem solving skills by solving puzzles?

- What features of generic thinking skills are enhanced by solving puzzles from the students' perspectives?

Pilot Study 1 - Results

Question 2. Can solving puzzles enhance your problem solving skills?

Yes – 98% In which way?

- Helps your brain to think more logically and becomes challenging
- Make you look at problems from different angles
- Broadens mind for alternative solutions
- Think in a different perspective, outside the box
- Showing that thinking differently can have amazing results
- Make me think creatively, not always relying on conventional/trained ways of problem solving
- Puzzles place an emphasis on HOW you tackle the problem
- Ability to think with multiple perspectives
- It allows me to come to a solution faster
- Need more puzzles in all maths papers ☺

No – 2% Why not?

- Too different

Pilot Study 1 - Results

Question 3. From you point of view, what are the main differences between puzzles and routine problems/questions?

- Puzzles are more fun to solve; more enjoyable and interesting
- Puzzles are more challenging because of the flexibility in approaching
- Puzzles require creative thinking and more careful reading
- Puzzles add a bit more variety; are more tricky, freshen up your mind
- Puzzles require more insight, creativity; more thinking and novel solutions
- A puzzle requires us to throw away those old/stubborn stuff in my brain in order to solve it
- Puzzles relate to more realistic things
- Puzzles are exciting and help to keep me alert
- Puzzles set a more fun environment compared to routine problems
- Puzzles test your problem solving skills and routine problems are testing if you can follow problems

Pilot Study 2 - Results

Question 1. Can solving puzzles enhance your problem solving skills?

Yes – 97% In which way?

- Gets you to think outside the box (>30)
- Being able to approach questions differently (>20)
- When it comes to solving practical problems in life (>20)
- Promotes learning using realistic situations (>10)
- You develop a more logically wired brain and you think about problems more open-mindedly (>10)
- Forces you to think creatively (it develops creative thinking which is important when facing non standard exam questions) (>5)
- These problems relate to problems engineers may come across in real life, and solving them is good experience (>5)

No – 3%

Pilot Study 2 - Results

Question 2. Can solving the puzzles enhance your generic thinking skills?

Yes – 97%

- By making you think about different situations in alternative ways (>20)
- It is about learning to think logically and methodically (>10)
- It will make students think about their theoretical solution and compare it with real world situations (>10)
- Use creative part of brain to decide on best answer (they are just really good at getting you to think creatively) (>5)
- You tend to see everyday life as puzzles you can solve (>5)
- Makes you think in practical ways
- Require us to step back and think in a broader scale

No – 3%

- They don't help learning
- Puzzles can be confusing

Pilot Study 2 - Results

Question 3. Can you see any other benefits for you in solving the puzzles?

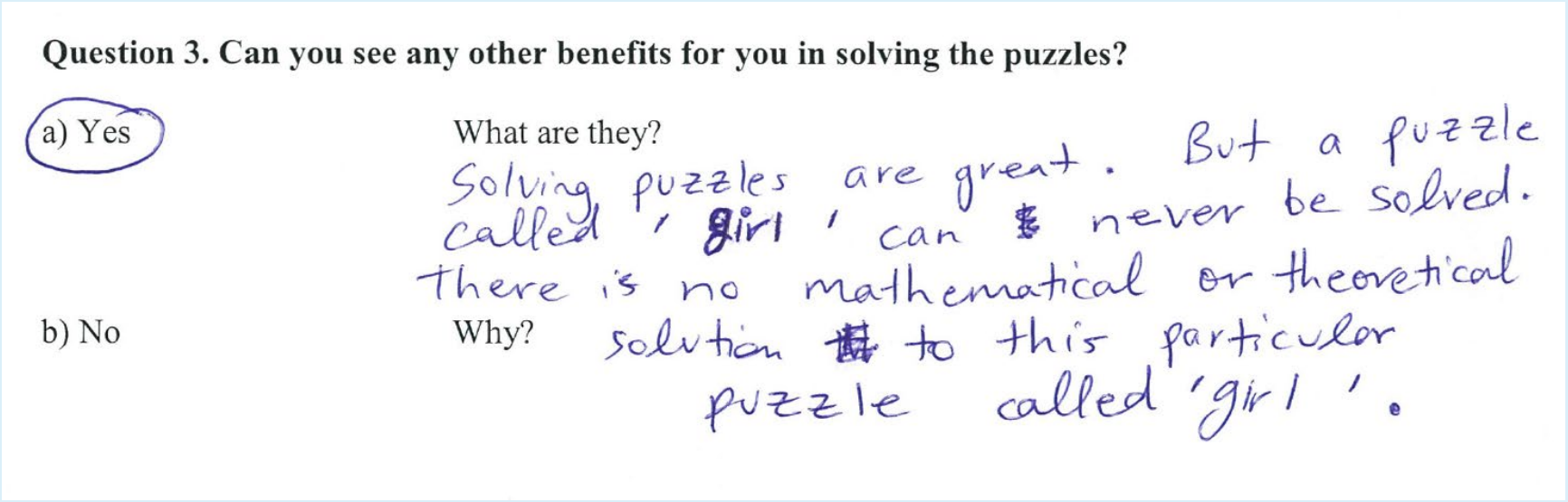
Yes – 82% What are they? (continued)

- It gives you a sense of accomplishment (learning patience/perseverance)
- You learn to filter out the useful, relevant info from the pointless
- Not being constrained in plugging numbers into equations
- It will come later in practical situations

No – 18% Why?

- The main benefits are given in questions 1 and 2
- Already covered in other subjects
- Don't learn basic maths techniques
- Puzzles may tend to throw off people even though it's an excellent method of testing
- Maybe – too tired to think

The Most Unexpected Comment



Question 3. Can you see any other benefits for you in solving the puzzles?

a) Yes (circled)

What are they?

Solving puzzles are great. But a puzzle called 'girl' can never be solved. There is no mathematical or theoretical solution to this particular puzzle called 'girl'.

b) No

Why?

Conclusions from Studies 1 & 2

- About 80% of the participants' favourable comments on enhancing their problem solving and generic thinking skills by solving puzzles were related to creativity
- The participants connected the relatively clear concept of problem solving skills and the vague concept of generic thinking skills with such features of creativity as originality, flexibility and divergent thinking from Guilford model of creativity and with 'overcoming fixations' and flexibility of thought from Haylock model

Guilford Model of Creativity

- There are more than 100 definitions of creativity!
- According to Guilford creative thinking is divergent thinking based on:

a. Fluency – generating many solutions
b. Flexibility – suggesting variety of approaches
c. Originality – proposing unusual approaches
d. Elaboration – implementing ideas

Conclusions from Studies 1 & 2

- Many students who successfully solved the puzzles were not among the top achieving students in the room
- A student who found a simple elegant solution to a puzzle is "not necessarily the most experienced or mathematically knowledgeable participant" (Koichu, Israel)
- "By applying learned strategies, a student can systematically apply multiple methods to solve a problem but never diverge into a creative strategy, never exploring areas outside the individual's known content-universe." (Mann, USA)

Pilot Study 3 (sem 2, 2016)

- **Support:** funded by a grant from Ako Aotearoa
- **Team:** four lecturers involved from stage II mathematics and physics courses
- **Intervention:** non-routine problems used in lectures at two universities: AUT and UoA
- **Aim:** to improve employability prospects of tertiary graduates
- **Means:** by developing students' capabilities to solve non-routine problems in contexts that are relevant to the workforce of the future

Study Design

We conceptualise the main phenomena by utilising the framework of **Motivational Influences on Transfer of Learning** (Pugh and Bergin (2006));

- Educational psychology: the issue of whether and how learning transfers to new settings
- **Transfer** refers to whether and how students access and apply their learning in novel contexts
- A tool of our analysis aligns with one of the four motivational constructs – **self-efficacy**

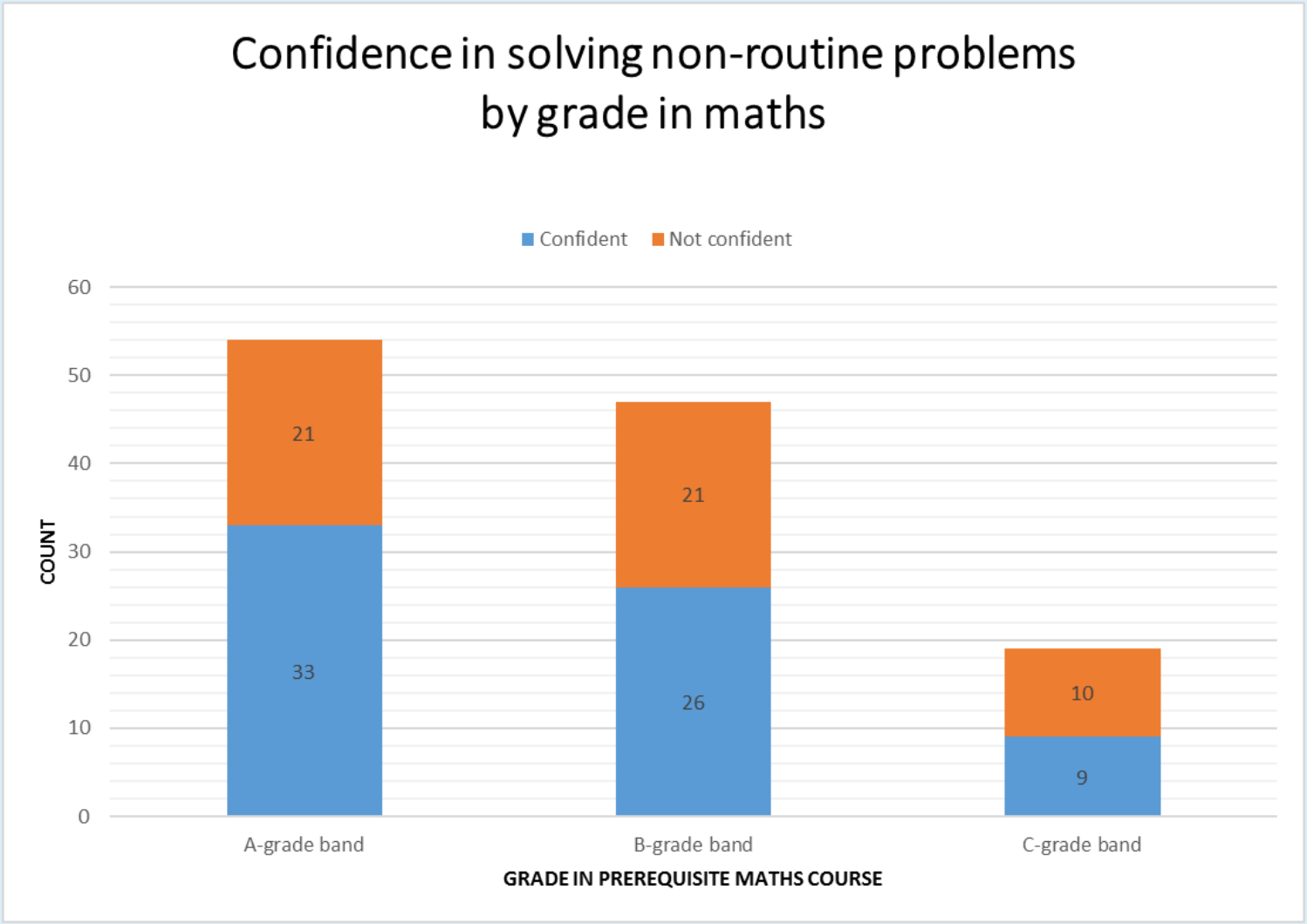
Self-efficacy

- the lens that we use to investigate the mechanisms involved in transfer of learning in the context of non-routine problem solving

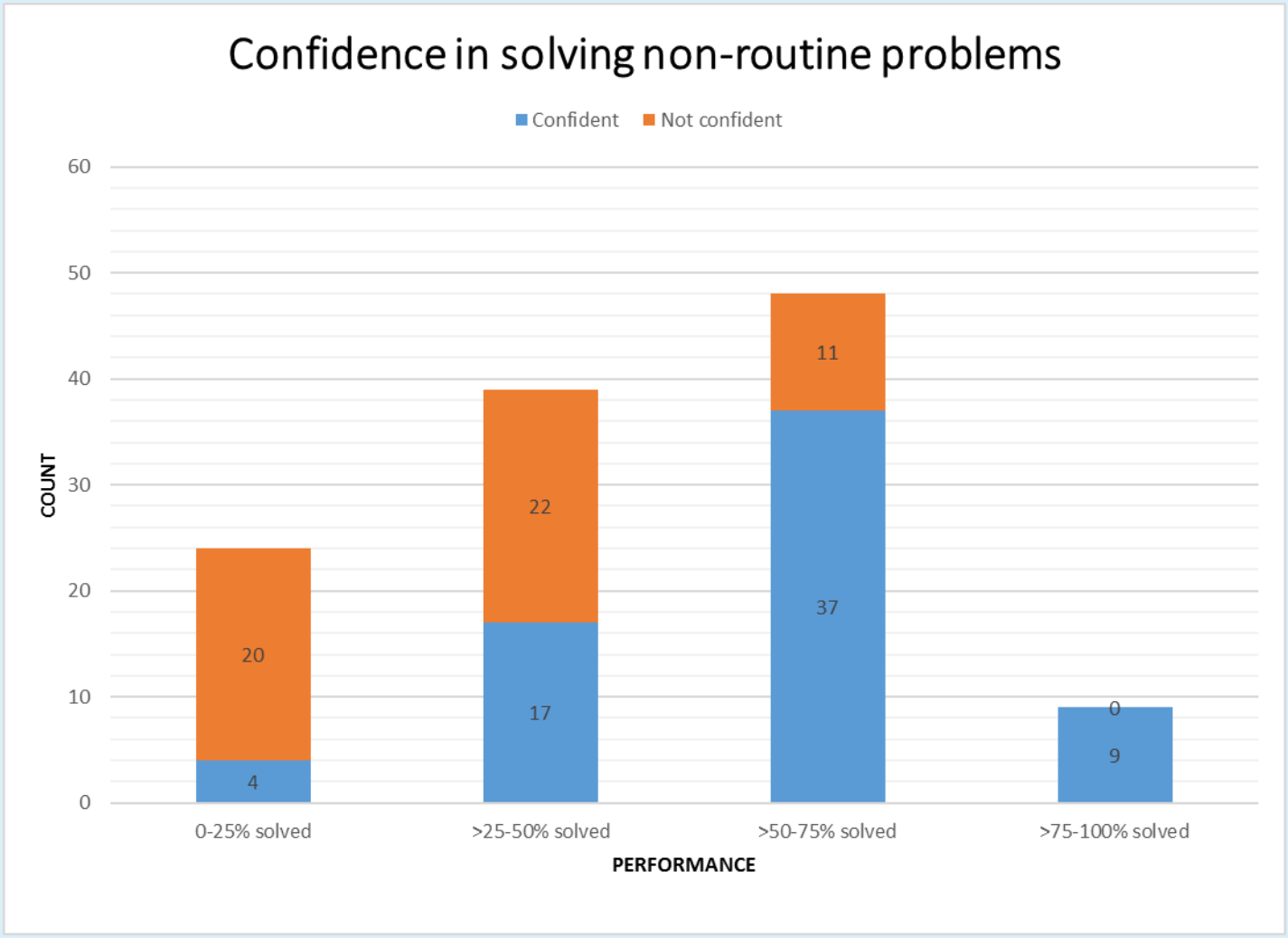
- more specifically: ‘In the context of transfer, self-efficacy usually refers to **confidence** in the ability to do or learn a skill that can transfer to another domain’ (Pugh and Bergin (2006))

Data collection

- Retrospective reports from 137 students (Questionnaire: 10 questions)
- In-depth interview with five participants



The Chi-square test for independence: statistic $\chi^2=1.13811$, $p=0.5661$. The result is not significant at p-value <0.05. No association between the categorical variables: performance in maths does not say anything about confidence in solving non-routine problems.



17% **44%** **77%** **100%**

The Chi-square test for independence: statistic $\chi^2(3)=33.2097$, p-value <0.000001. The result is significant at p-value <0.05 implying that an association between the variables has been observed. The effect size of the association is measured by Cramér's V=0.53 which is substantial.

Findings: self-efficacy

‘In the context of transfer, self-efficacy usually refers to **confidence** in the ability to do or learn a skill that can transfer to another domain’ (Pugh and Bergin (2006)).

We observed that there is an association between students’ performance in solving non-routine problems during one semester course (with only 5-7 min of activity per week) with confidence in solving non-routine problems.

Conclusions

Basing our analysis on the framework of the **Motivational Influences on Transfer of Learning,** we demonstrated how we can improve students' confidence in solving non-routine problems, hence suggesting a positive affect on students' self-efficacy in the context of transfer to novel domains.

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We also showcased how it can be done as a small-scale tuning of teaching/leaning practice at university.

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Basing our analysis on the framework of the **Motivational Influences on Transfer of Learning,** we demonstrated how we can improve students' confidence in solving non-routine problems, hence suggesting a positive affect on students' self-efficacy in the context of transfer to novel domains.

We also showcased how it can be done as a small-scale tuning of teaching/leaning practice at university.

This method is amenable to scaling-up across STEM curricula, which can help to develop students' capabilities to solve non-routine problems in contexts that are relevant to the workforce of the future.

Current Project

Funded by NZ government grant (TLRI)

– value $200,000

Team:

PI A/Prof Sergiy Klymchuk, AUT

PI Emeritus Prof Mike Thomas, UoA

PI Dr Tanya Evans, UoA

AI A/Prof Jason Stevens, UoA

AI Dr Julia Novak, UoA

and five practitioners

Current Intervention Trial

- five groups of students from four diverse tertiary institutions (about 700 students)
- their learning has been enhanced by the addition of puzzles (<5 min per lecture – as a break in the middle)

Aiming to analyse the impact on learners' creativity, engagement and ability to inhibit intuitive thinking.

Data:

Pre-test, post-test (incl. Cognitive Reflection Test, CT, DT), video-recorded focus groups, and observations of lectures.

Future Research

- **Evaluate** the relationship between the ability in solving puzzles and course performance
- **Measure** creativity using Torrence Creativity Test before and after the regular use of puzzles
- **Investigate** the effect of using puzzles on student engagement and attendance
- **Analyse** the impact of using puzzles on a student decision to continue their study (retention)
- **Measure** the cognitive dimension of the student engagement (investment in learning, perseverance in the face of challenges, and use of deep rather than superficial strategies)

Thank you for your attention

and

what about the Chocolate Bar Puzzle?

More Puzzles

Puzzle-1

Imaging a rope lying around the Earth's equator without any bends. You add 20 metres to the rope and form a circle again. How high approximately will the rope be above the Earth:

A) 3mm B) 3cm C) 3m?

Answer: 3m

Let ***r*** be the radius of the Earth and ***R*** be the radius of the circle after adding 20m to the rope. The difference between the two circumferences is 20m:

$$2\pi R - 2\pi r = 20m \quad \Rightarrow \quad 2\pi(R - r) = 20m$$

$$R - r \approx 3m$$

Puzzle-2

Certain bacteria double in numbers every second. If you placed one such bacterium on an empty plate it would take 1 minute for bacteria to fill it. How long would it take to fill the same plate if you initially put two bacteria on the empty plate?

Answer: 59 seconds

Since we start with 2 bacteria, we have one step less, namely reproducing the first bacterium into two, which takes one second.

Puzzle-3

Two 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?

Answer: the water level goes down

As an alternative way, one can use the Extreme Values Principle. Imagine that the cannonball is very-very heavy, say 500 kg but has a size of a tennis ball, that is the density is very high. When you remove the heavy cannonball from the canoe, the canoe submerges less and the water level goes down considerably. When you drop the cannonball of such a small size into the pool it will push the water level up but very-very little.

Puzzle-4
(job interviews at Microsoft)

Crossing the Bridge. Four people – John, Paul, George and Ringo – are at one side of a gorge connected to the other by a rope bridge that can only carry two people at a time. It is a night time, so whoever is crossing must use a torch. The group has a single torch, and the gorge is too wide for them to be able to throw it from one side to the other, so the torch must be walked back and forth over the bridge as the people cross. John can cross the bridge in 1 minute, Paul in 2, George in 5 and Ringo in 10. If two people cross together, they walk at the speed of the slowest of the two. How do the group cross the bridge in the quickest possible time? What is the quickest time?

Puzzle-4
(job interviews at Microsoft)

The most common answer is 19 minutes

But… you can do better (quicker)

Answer: 17 minutes

At the second crossing you put the two slowest people together.

Final Thanks!