Northern Regional Hub-funded project

Project Report

Enhancing generic thinking skills of tertiary STEM students through puzzle-based learning

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September 2017

Executive Summary

The aim of the project was to evaluate the impact of the regular use of puzzles, paradoxes and sophisms (PPS) as a pedagogical strategy for enhancing generic thinking skills of tertiary STEM students'. A significant number of tertiary STEM students drop out from their study during the first-year not because the courses are too difficult but because, in their words, they 'are too dry and boring'. There are even such terms as emotional disengagement and academic disinterest. The intention of using PPS in teaching/learning is to engage students' emotions, creativity and curiosity and also enhance their critical thinking skills and lateral thinking "outside the box". The theoretical considerations of the project were based on the Puzzle-Based Learning (Michalewicz & Michalewicz, 2008) concept that has become increasingly popular worldwide. The impact of the suggested pedagogical strategy was evaluated via comprehensive questionnaires, interviews and class observations involving 137 STEM students from four groups at AUT and the University of Auckland. The vast majority of the participants reported that the regular use of PPS helped them to enhance their problem-solving (91%) and generic thinking skills (92%). Apart from improving those skills, 82% of the participants commented on other various benefits from using this pedagogical strategy. After analysing the observed overwhelming positive students' attitudes we suggest that there is a need for further and more rigorous investigation of the suggested pedagogical strategy.

AKO AOTEAROA
NATIONAL CENTRE FOR TERTIARY TEACHING EXCELLENCE

An Ako Aotearoa publication.
This project output has been funded by Ako Aotearoa through the Regional Hub Project Fund.

Contents

Rationale and Theoretical Considerations

In 2012 the New Zealand government identified the need to reduce the undersupply of students studying STEM subjects as a priority for delivering its Business Growth Agenda (www.mbie.govt.nz). Obviously, low engagement and retention rates in STEM subjects contribute to the shortage of STEM graduates, producing a negative impact on the New Zealand economy. The aim of the project was to enhance tertiary STEM students' generic thinking skills through the regular use of puzzles, paradoxes and sophisms (PPS) as a pedagogical strategy. By a puzzle we mean a non-standard, non-routine, unstructured question presented in an entertaining way. Some authors treat a puzzle as an antithesis to a routine problem that "can be solved only through long, complex calculations, which tend to be mechanical and boring, and often drudgery for students" (Gnadig, Honyek & Riley, 2001). Often authors distinguish a puzzle and a procedural problem: "One good characteristic of puzzles is that they cannot be solved by rote; puzzles are invaluable in making students think" (Thomas et al., 2013). By a paradox we mean a surprising, unexpected, counter-intuitive statement that looks invalid but in fact is true. By a sophism we mean intentionally invalid reasoning that looks formally correct, but in fact contains a subtle mistake or flaw. According to Thomas et al. (2013) the teaching and learning process often loses its effectiveness as a result of insufficient involvement and emotional investment from students. The intention of using PPS in teaching/learning is to engage students' emotions, creativity and curiosity and also enhance their critical thinking skills and lateral thinking "outside the box". The theoretical considerations of the project are based on the Puzzle-Based Learning approach developed by Michalewicz and Michalewicz (2008). This approach becomes increasingly popular worldwide. Preliminary feedback from lecturers and researchers is very promising. Falkner et al. (2012) reflected on a puzzle-based course for computer science students: "The benefit to the student goes beyond the short course that they take part in, or any course-specific skills, as the lessons learnt may be applied to every other course in which they participate… The skills that they learn in puzzle-based learning are far more than games." (p.267). A similar positive feedback on extensive and regular usage of the puzzles in the teaching of engineering mathematics is reported in (Thomas et al., 2013): "Firstly, puzzles might be recast into an engineering (or STEM) context, as discussed later, making them less abstract, more concrete, and presumably more acceptable to the typical student. Secondly, it is fortunate that many puzzles are accompanied by a diagram, or the creation of a diagram is an essential first step in finding a solution. Finally, sets of puzzles can be selected and arranged to provide sequential learning, especially in their underlying mathematics, and an alternative is to embed puzzles in other teaching such as engineering mathematics problem classes." (p.128). Apart from enhancing generic thinking skills and increasing motivation solving puzzles can be a good preparation for a job interview. Many companies use puzzles during their job interviews to evaluate candidate's general problem solving skills and select best of the best. A classic example is Microsoft: "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. When technology is changing beneath your feet daily, there is not much point in hiring for a specific, soon-to-be-obsolete set of skills. You have to hire for general problem-solving capacity, however difficult that may be." (Poundstone, 2000). This issue is also very important and timely in the New Zealand context. At the launch of the AUT's STEM Tertiary Education Centre (STEM-TEC) in 2014 Hon Steven Joyce commented that many New Zealand innovative high-tech companies could not 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 needed more than that – they needed candidates with highly innovative and creative thinking skills. This is consistent with the Vision Mätauranga (2005) that encourages a spirit of creativity and innovation, in particular for research and development as "the place where creative thinkers focus on key issues, problems and creative possibilities" (p. 22). As Sir Paul Reeves said at Hui Taumata on 1 March 2005: "We are geared toward innovative and revolutionary thinking, and practical and sustainable solutions". Such thinking is paramount for STEM education that is cross-disciplinary, multi-disciplinary and inter-disciplinary by its nature and therefore it is in line with the knowledge weaving theme of indigenous knowledge suggested by mätauranga Mäori: "the weaving of knowledge across different domains, in a cross-disciplinary and cross-cultural style" (p. 16).

Project Design and Demographics of Participants

The impact of the suggested pedagogical strategy was evaluated via comprehensive questionnaires, interviews and class observations involving 137 STEM students from four groups at AUT and University of Auckland. Two groups studied general mathematics, one group engineering mathematics and one group astronomy. There were many other STEM courses at both institutions. The lecturers in the four groups were using PPS in their classes in semester 2 2016 on a regular basis – at least three PPS a week. The participants for the study were selected using a combination of convenience and judgement sampling methods. One hundred and thirty-seven students completed the questionnaire and five of them were interviewed. The average response rate for the questionnaire in the four groups was 96%. The age distribution was as follows: 44% were younger than 20 years old (y.o.); 51% between 20 and 30 y.o; and 5% older than 30 y.o. There were 60% male participants and 40% female; 73% were domestic students and 27% international. The puzzles did not contribute to the students' grade.

Findings

The questionnaire comprised 10 questions including 3 on demographics. One question was about students' performance in solving puzzles during semester 2 2016 and one question about students' performance in the pre-requisite course. The questionnaire is attached in Appendix 1. A detailed analysis was performed on the relationships between the four main questions on confidence in solving puzzles; enhancing problem-solving skills; enhancing generic thinking skills; other benefits in solving puzzles and five questions on students' performance and demographics. Students' comments for each question were categorized and presented as graphs. The total number of graphs produced as part of analysis of the data is 30. Examples of the graphs are given in
Appendix 2. The interview questions are attached in Appendix 3.

<u>The main findings from the questionnaire</u>

Question 1: From your point of view, what are the main differences between puzzles and routine problems/questions?

34% - More creativity/Critical/Lateral thinking in puzzles

28% - Routine problems are straightforward/less applicable

14% - Puzzles are for leisure/fun

13% - Puzzles are more challenging/practical

4% - No difference

7% - Other comments (Completely different, puzzles are not examinable, etc.)

Question 2: Do you feel confident solving the puzzles?

54% - yes

46% - no

The reasons stated by students to support their confidence in solving puzzles included: Puzzles are easy; Applicable to real life; Challenging; Enhances thinking skills; and A solution is reachable.

Some reasons stated by students who were not confident in solving puzzles were: Inexperienced in puzzles; Puzzles are tricky/different; and Not listening in class.

We also used comparative analysis:

Against performance in a previous maths course: Interestingly we note that 40% of students with an A in a prerequisite course are not confident in solving puzzles.

Against gender:

We note an imbalance in gender vs confidence reporting, with significantly more females (56%) not feeling confident in solving puzzles compared with 38% of males who felt the same.

Against residency status:

Interestingly there was almost no difference in confidence in solving puzzles between domestic and international students.

Question 3: Do you think solving the puzzles can enhance your problem solving skills?

91% - yes

9% - no

Using comparative analysis we note that there was not much difference in the responses among students who were able to solve most puzzles and students who were only able to solve less than 25% of the puzzles in class – an overwhelming majority (88% and 84% respectively) thought that their problem-solving skills would be enhanced by practising puzzle solving.

Question 4: Can solving the puzzles enhance your generic thinking skills?

92% - yes

8% - no

We note that 49% of students commented that solving puzzles enhances their generic thinking skills because it is challenging and improves creativity;

19% of students noted that thinking skills are enhanced because puzzles are applicable to real life problems.

Also, 16% stated that enhancement of thinking skills is achieved by improvement in pattern recognition.

Further comparative analysis revealed:

Against performance in a previous maths course: Interestingly we note that there is no difference in perception of the value of PPS between students from A-band and C-band grade cohorts, with 84% of students stating that puzzles enhance their generic thinking skills, whereas an even higher proportion of the B-band grade group stated the same (96%).

Against gender and residency status:

There was not much difference in the responses among these groups.

Against ability to solve puzzles: We note that even among the students who were able to only solve less than 25% of the puzzles in class, the majority (76%) thought that their generic thinking skills were enhanced by practising puzzle solving.

Question 5: Can you see any other benefits for you in solving the puzzles?

82% - yes

18% - no

We note that among the students who were only able to solve less than 25% of the puzzles in class, the majority (52%) saw no other benefits in solving puzzles. Also, interestingly a significantly higher proportion of international students perceived extra benefits in puzzle solving compared with domestic students – 86% and 67% respectively.

The main findings from the focus group interviews

During the focus group interviews participants were asked a series of questions:

Can solving puzzles enhance your creativity? If so, in what way? All five participants agreed that solving puzzles enhances creativity. For example, students said the following:

"Yes: rather than using a given equation or method puzzles help creativity as they use logic and idea generation. Coming up with alternative ways of doing a puzzle is far more intellectually stimulating than a math course."

"Yes. Puzzles can, sometimes, cultivate the creative thinking in a person, no matter it is maths related or not. It encourages thinking independently greatly."

Is there any connection between the ability to solve puzzles and innovative thinking? Can you give any examples? All participants agreed that there is a connection between the ability to solve puzzles and innovative thinking. Moreover, comments from some of the students implied that practising puzzle solving improves one's innovative skills. For example the students said: *"I believe so. As above, having to find your own way to a solution expands your mind/thought process. Should allow for more innovative thought."*

"Yes, sometime when you see the puzzle and try to solve it and failed it, you will think more and more. And also, sometimes accidentally you will find a new way and being innovative. I have tried one of difficult riddle on Youtube, then they give me the answer, even though my answer is correct, but I have better way to get it right and faster than them."

Would you like to see puzzles in other courses? Four out of five students said that they would like to see puzzles in other courses. However one student felt strongly that puzzles should only be offered outside the classroom:

"I think problem solving is important but learning relevant class material is more so. For this reason I think it should be optional, eg. Watch a quick Youtube video after class."

This was also supported by a few comments along the same lines from students completing the questionnaire.

Several comments referred to social aspects that are brought into a lecture by including puzzles:

'As well as being effective exercises, they are also a lot of fun to do in class. It's good change of pace when an open-ended problem is presented and we are encouraged to work together.'

Do you think solving the puzzles helped your mathematics? If so, in what way?

Does solving puzzles motivate you to study more mathematics?

"Yes and yes. They forced me to think of problems mathematically, but beyond simply plugging in numbers to a known method and computing a solution. It showed me that with more mathematics, I would be able to have more tools to solve other problems."

"Not mathematics specifically no, but I think they allowed for a different method of thinking that is helpful in general, which helps us to approach problems differently. With math, I feel like there's a specific formula you must use to find the answer & if it's wrong then you will get a wrong answer. So I don't think puzzles help with that, plus I think they're more of a "brain exercise" that keeps our mind active."

The students also offered some suggestions on how best to incorporate puzzle solving into courses – one suggested including them as part of the tutorials and possibly setting up a competition between small groups. Another student suggested including puzzles in tests and exams to increase motivation.

After analysing all the data collected and being encouraged by the mostly positive student feedback we suggest that there is a need for deeper and more rigorous investigation of the aspects of this pedagogical strategy in order to evaluate its impact on creativity and other learning outcomes. Many research questions can now be posed to establish the optimal way of incorporating puzzle solving into tertiary STEM education.

Project Outputs

Below are outputs from this project and previous similar AUT pilot project that informed the current project.

1. Evans, T., Klymchuk, S., Thomas, M. (2017). Improving graduate attributes of students: researching the impact of regular use of non-routine problem solving on creativity and general thinking skills of STEM students. To be presented at the New Zealand Mathematics Colloquium – December (accepted).
2. Evans, T., Klymchuk, S., Thomas, M. (2017). Creative thinking skills as a learning outcome for tertiary STEM students – researching the impact of the regular use of non-routine problem solving as a pedagogical strategy. To be presented at the Tertiary Education Research in New Zealand conference – November (accepted).
3. Evans, T. & Klymchuk, S. (2017). Enhancing generic problem-solving and thinking skills of tertiary STEM students through Puzzle-Based Learning. Presented at the *NZ National Tertiary Learning and Teaching Conference* 2-3 October.
4. Klymchuk, S. (2017). Puzzle-Based Learning in Engineering Mathematics: Students' Attitudes. *International Journal of Mathematical Education in Science and Technology*, published online 15 May. http://dx.doi.org/10.1080/0020739X.2017.1327088.
5. Klymchuk, S. (2016). *Enhancing engineering students' generic thinking skills through puzzles, paradoxes and sophisms*. Presented at the seminar at the STEM Tertiary Education Centre, Auckland University of Technology, New Zealand.
6. Klymchuk, S. (2016). Enhancing general thinking skills through puzzles, paradoxes and sophisms: Engineering students' perspectives. In *Online proceedings of the 3rd Mathematics Education and Contemporary Theories conference (MECT-3)* (pp. 9 pages). Manchester, UK: Manchester Metropolitan Univesrity. Retrieved from http://www.esri.mmu.ac.uk/mect3/papers-list.php
7. Klymchuk, S. (2016). Using counterexamples, puzzles and provocations in the teaching and learning of calculus. Presented at the *13th International Congress on Mathematical Education (ICME-13)*. Hamburg, Germany.
8. Klymchuk, S. (2016). *Enhancing Engineering Students' Generic Thinking Skills through Puzzles, Paradoxes and Sophisms*. Presented at the seminar at Centre for Research, Innovation and Coordination of Mathematics Teaching of the University of Agder, Norway.
9. Klymchuk, S. (2016). *Using counterexamples, puzzles and provocative questions as a pedagogical strategy to engage secondary mathematics learners*. Presented at the workshop at the Academy of Singapore Teachers, Singapore.
10. Klymchuk, S. (2016). Puzzles, paradoxes and provocations in calculus. In *Auckland Mathematical Association Mathematics and Calculus Teachers' Day Programme* (pp. 7-8). Auckland, New Zealand.

11. Klymchuk, S. & Evans, T. (2016). Enhancing generic thinking skills of tertiary STEM students through puzzle-based learning. In *Ako Aotearoa Northern and Central Hub's Projects Colloquium* (p. 10). Auckland, New Zealand: Ako Aotearoa National Centre for Tertiary Teaching Excellence.

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Thomas, C., Badger, M., Esther Ventura-Medina, E. & Sangwin, C. (2013). Puzzle-based learning of mathematics in engineering, *Engineering Education*, 8(1), 122-134.

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Appendix 1 Questionnaire

Question 1. From your point of view, what are the main differences between puzzles and routine problems/questions?

Question 2. Do you feel confident solving the puzzles?
a) Yes b) No Please give the reasons:

Question 3. Do you think solving the puzzles can enhance your problem solving skills?
a) Yes In which way? b) No Why not?

Question 4. Can solving the puzzles enhance your generic thinking skills?
a) Yes In which way? b) No Why not?

Question 5. Can you see any other benefits for you in solving the puzzles?
a) Yes What are they? b) No Why?

Question 6. Approximately how many puzzles did you solve correctly over weeks 7-12?

a) less than 25% b) between 25% and 50% c) between 50% and 75% d) more than 75%

Question 7. What was your grade in the course pre-requisite to this one?

A+ A A– B+ B B– C+ C C–

Question 8. What is your gender? a) Male b) Female

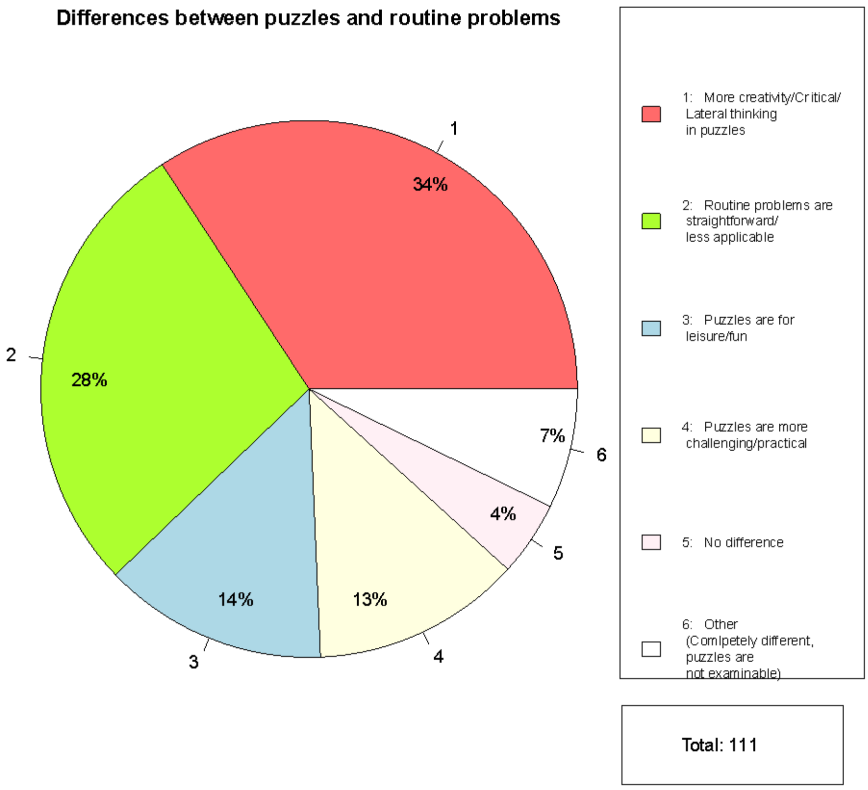
Question 9. What is your age group? a) younger than 20; b) 20-30; c) older than 30

Question 10. Are you a domestic student or international? a) domestic; b) international

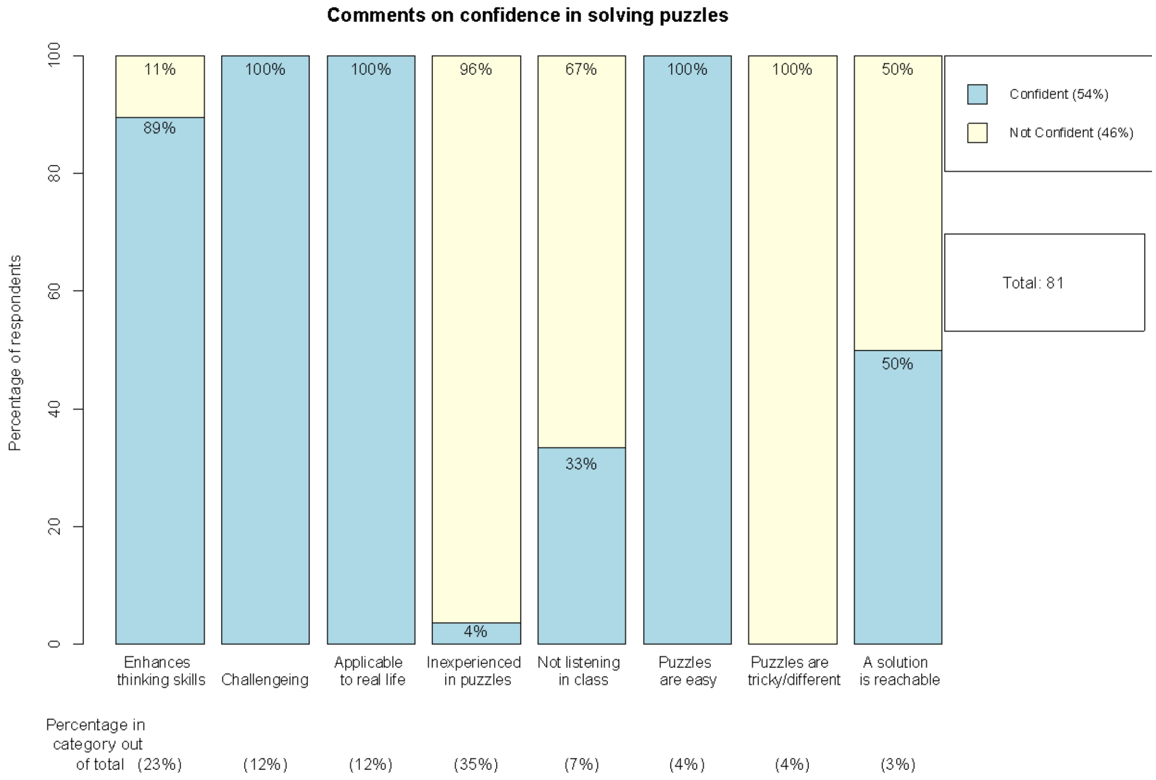
Thank you very much for your responses.

Approved by the UoA Human Participants Ethics Committee on 14/10/16 for 3 years. Ref. # **018102**

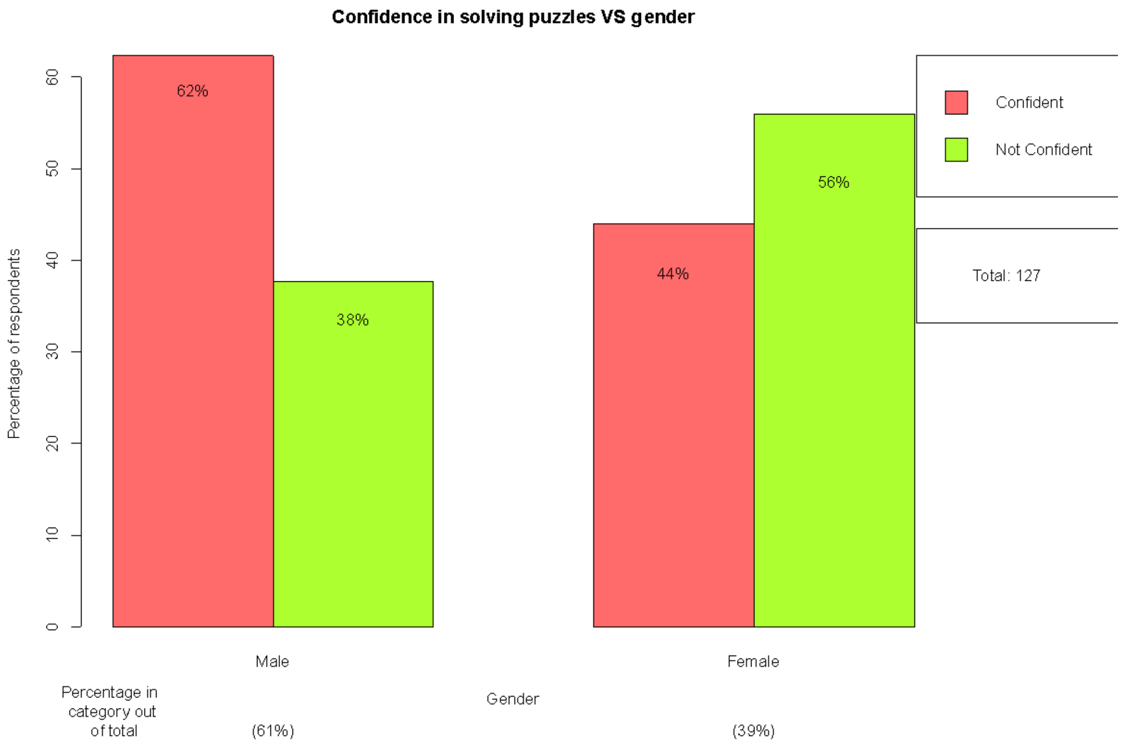
Appendix 2



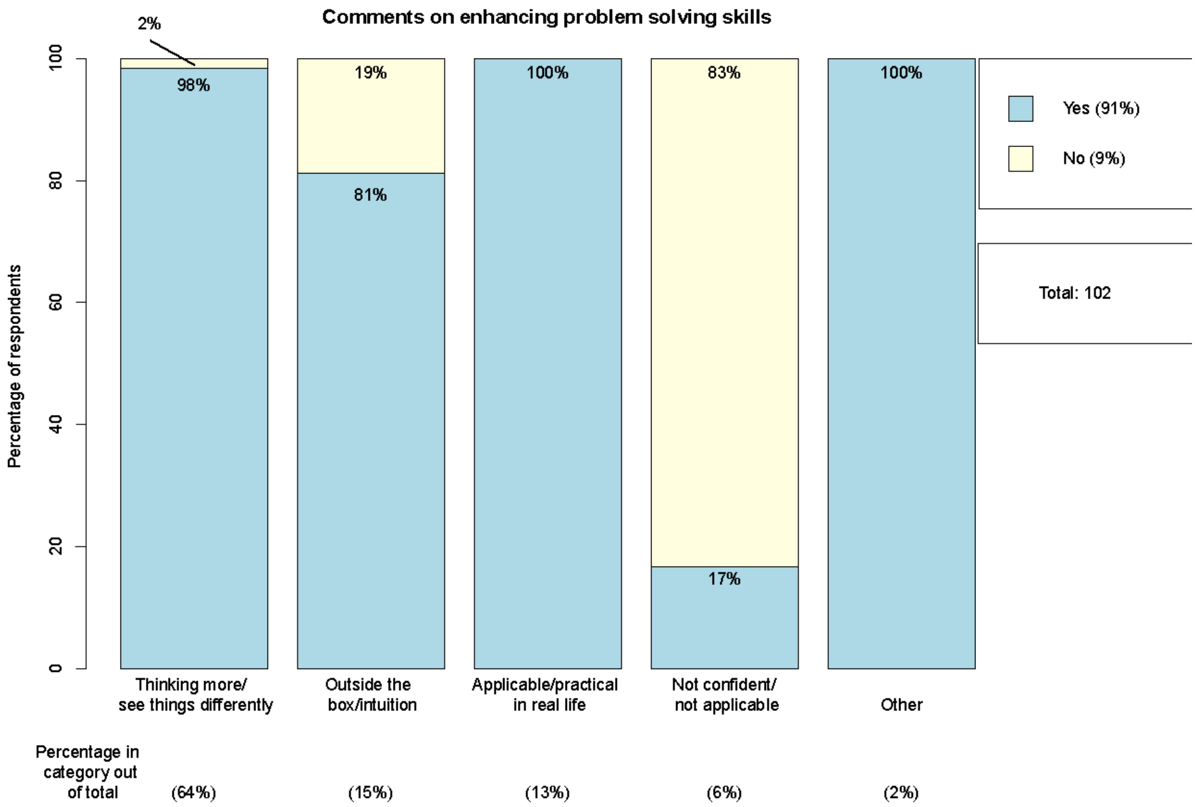
Differences between puzzles and routine problems
1
34%
2
28%
3
14%
4
13%
5
4%
6
7%
1: More creativity/Critical/ Lateral thinking in puzzles
2: Routine problems are straightforward/ less applicable
3: Puzzles are for leisure/fun
4: Puzzles are more challenging/practical
5: No difference
6: Other (Comlpetely different, puzzles are not examinable)
Total: 111

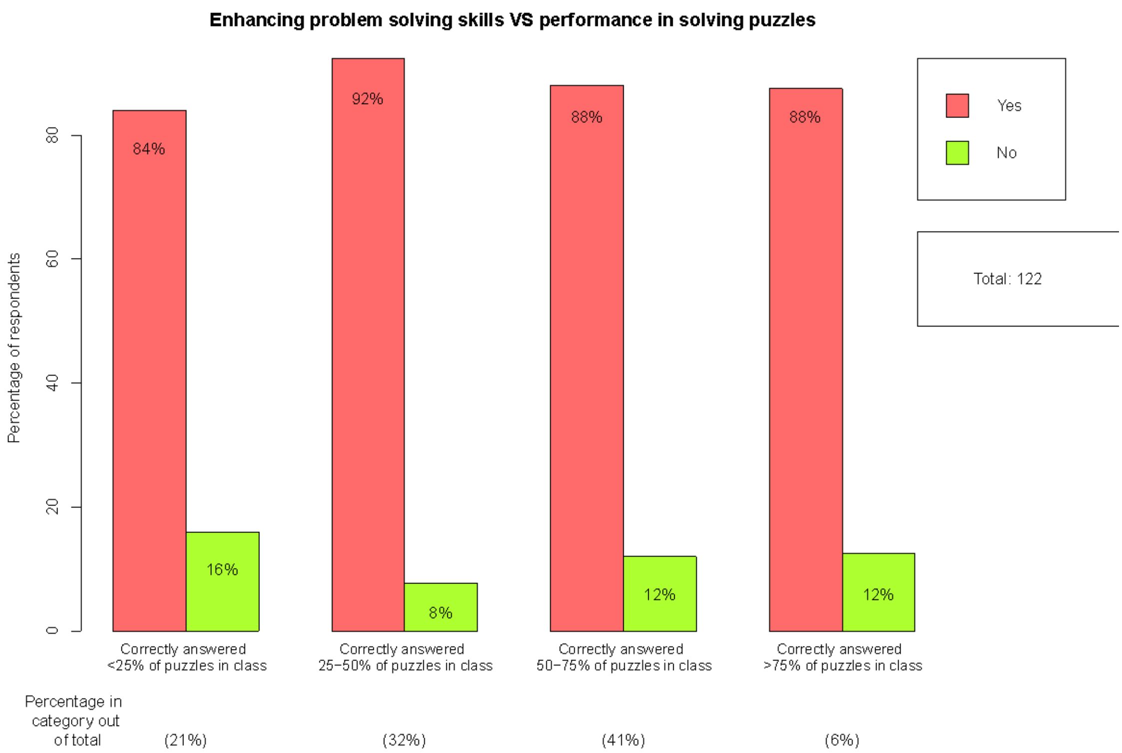


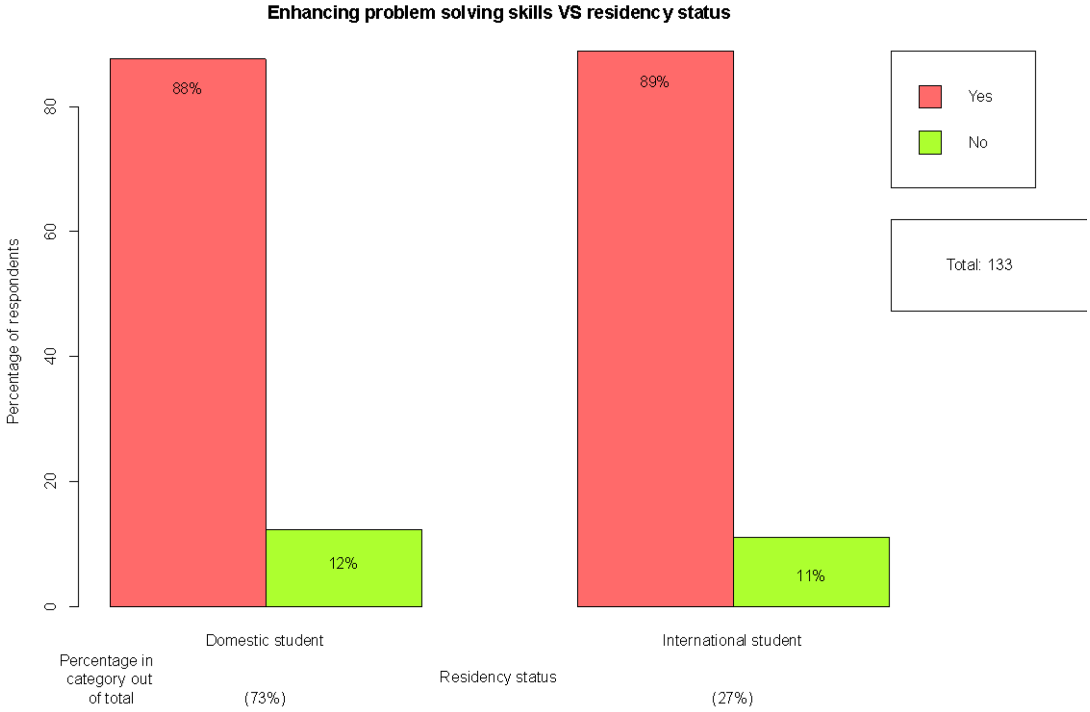
Comments on confidence in solving puzzles
Percentage of respondents
0
20
40
60
80
100
11%
89%
100%
100%
96%
4%
67%
33%
100%
100%
50%
50%
Confident (54%)
Not Confident (46%)
Total: 81
Enhances thinking skills
Challengeing
Applicable to real life
Inexperienced in puzzles
Not listening in class
Puzzles are easy
Puzzles are tricky/different
A solution is reachable
Percentage in category out of total
(23%)
(12%)
(12%)
(35%)
(7%)
(4%)
(4%)
(3%)

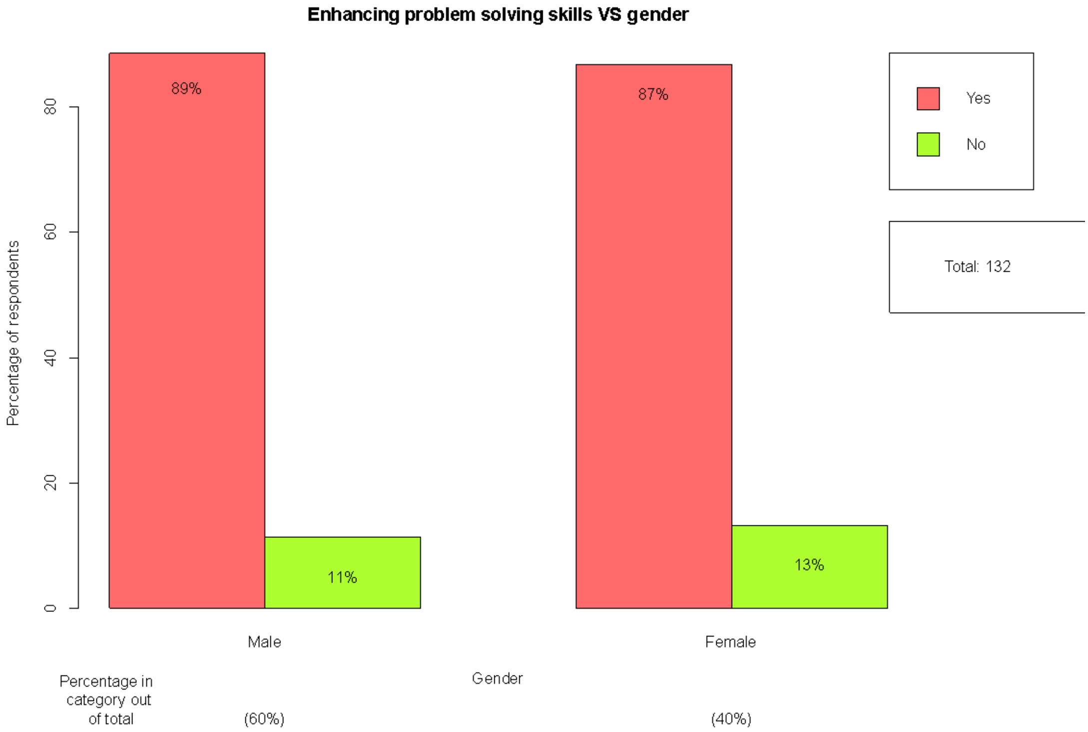


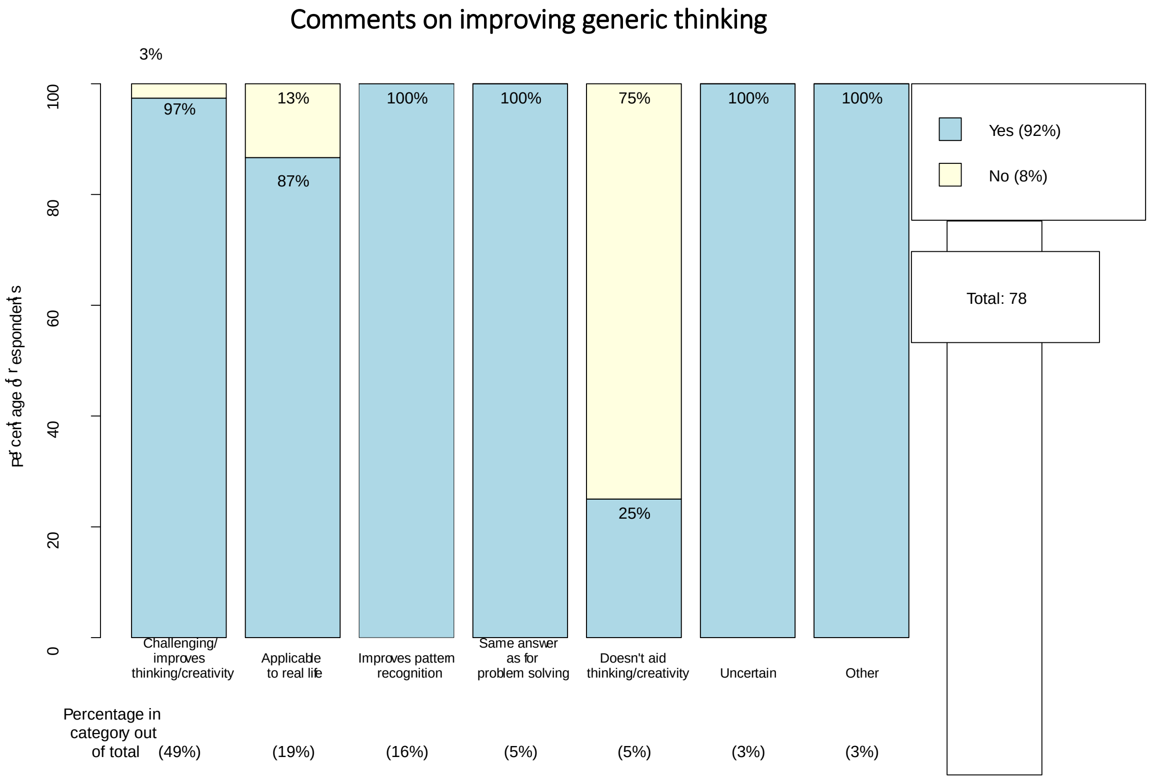
Confidence in solving puzzles VS gender
Percentage of respondents
0
10
20
30
40
50
60
62%
38%
44%
56%
Confident
Not Confident
Total: 127
Male
Female
Gender
Percentage in category out of total
(61%)
(39%)

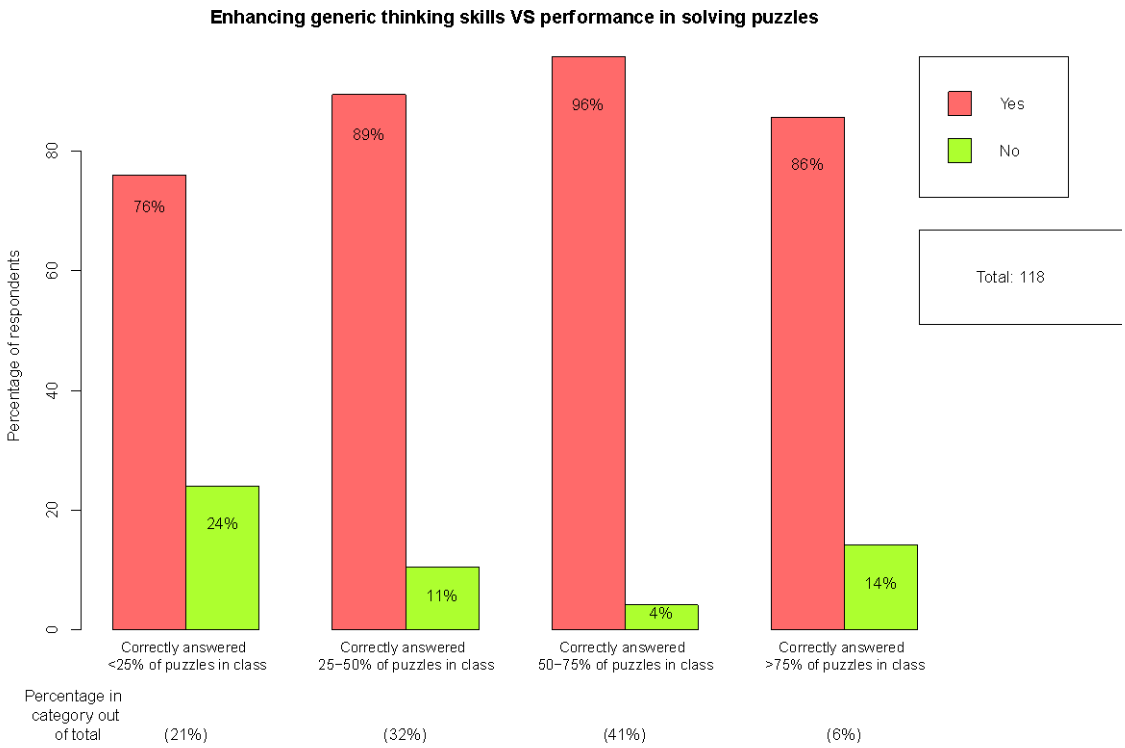

Comments on enhancing problem solving skills
Percentage of respondents
0
20
40
60
80
100
2%
98%
19%
81%
100%
83%
17%
100%
Yes (91%)
No (9%)
Total: 102
Thinking more/ see things differently
Outside the box/intuition
Applicable/practical in real life
Not confident/ not applicable
Other
Percentage in category out of total
(64%)
(15%)
(13%)
(6%)
(2%)

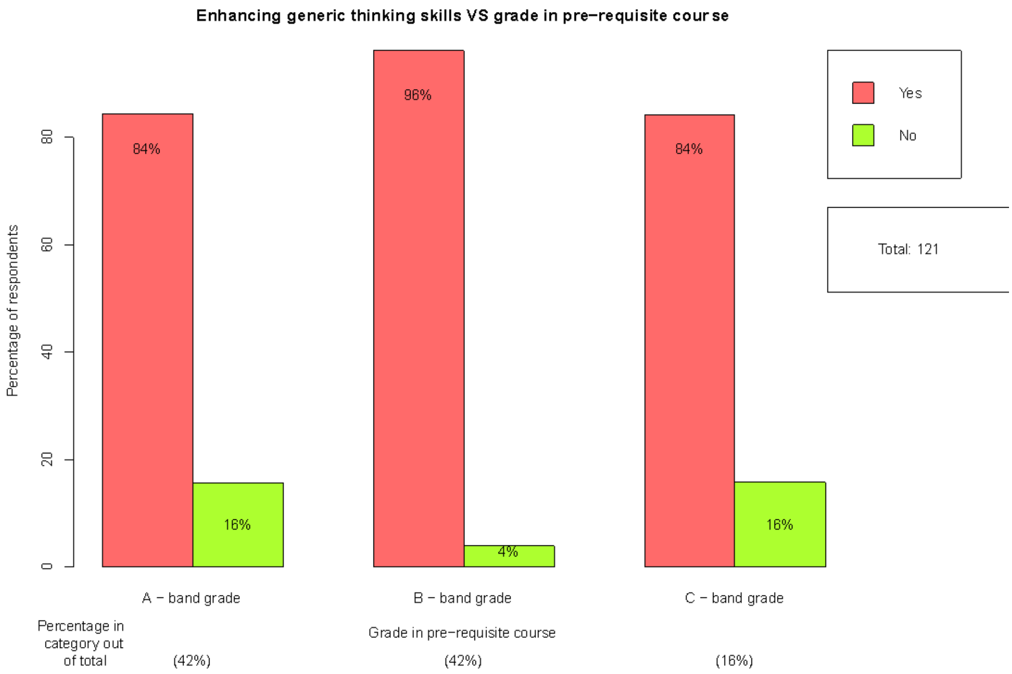

Enhancing problem solving skills VS performance in solving puzzles
Percentage of respondents
0
20
40
60
80
84%
16%
92%
8%
88%
12%
88%
12%
Yes
No
Total: 122
Correctly answered <25% of puzzles in class
Correctly answered 25–50% of puzzles in class
Correctly answered 50–75% of puzzles in class
Correctly answered >75% of puzzles in class
Percentage in category out of total
(21%)
(32%)
(41%)
(6%)


Enhancing problem solving skills VS residency status
Percentage of respondents
0
20
40
60
80
88%
12%
89%
11%
Yes
No
Total: 133
Domestic student
International student
Residency status
Percentage in category out of total
(73%)
(27%)

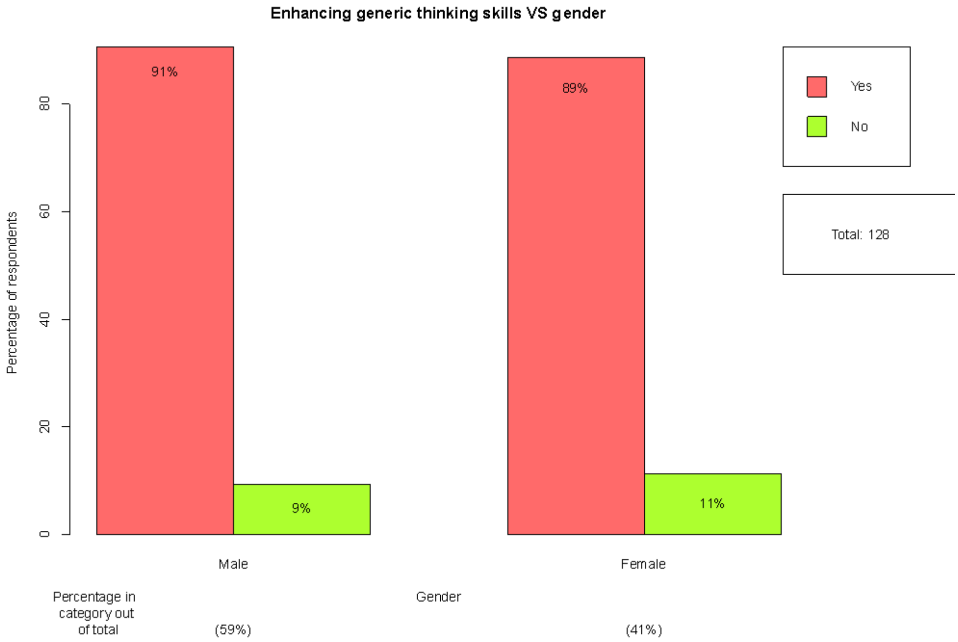

Enhancing problem solving skills VS gender
Percentage of respondents
0
20
40
60
80
89%
11%
87%
13%
Yes
No
Total: 132
Male
Female
Gender
Percentage in category out of total
(60%)
(40%)


Comments on improving generic thinking
Percentage of respondents
0
20
40
60
80
100
3%
97%
13%
87%
100%
100%
75%
25%
100%
100%
Yes (92%)
No (8%)
Total: 78
Challenging/ improves thinking/creativity
Applicable to real life
Improves pattern recognition
Same answer as for problem solving
Doesn't aid thinking/creativity
Uncertain
Other
Percentage in category out of total
(49%)
(19%)
(16%)
(5%)
(5%)
(3%)
(3%)

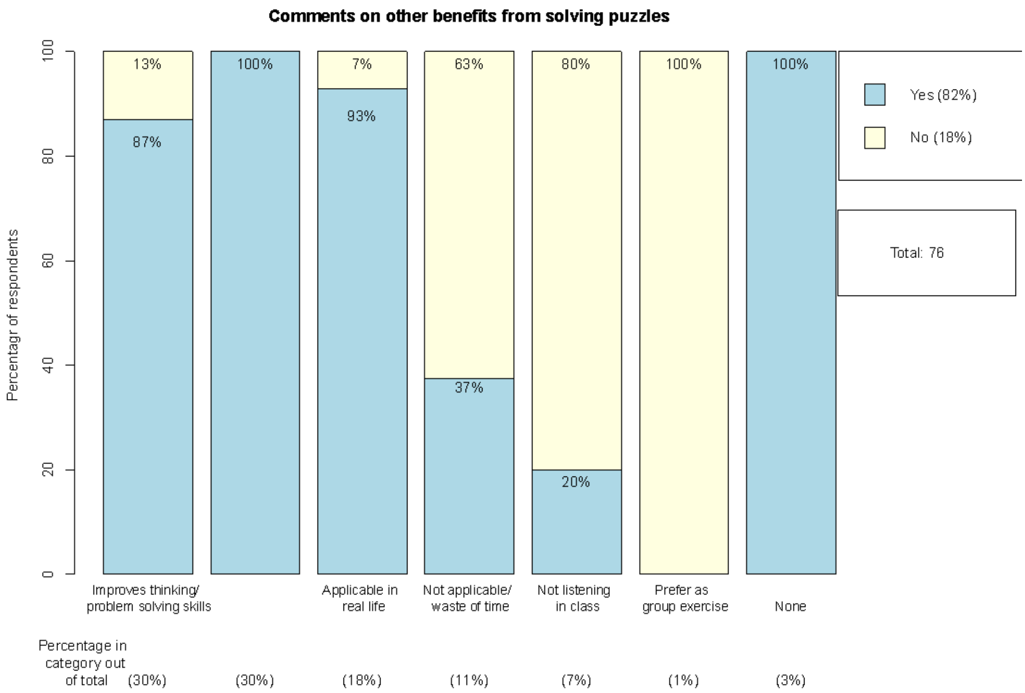

Enhancing generic thinking skills VS performance in solving puzzles
Percentage of respondents
0
20
40
60
80
76%
24%
89%
11%
96%
4%
86%
14%
Yes
No
Total: 118
Correctly answered <25% of puzzles in class
Correctly answered 25–50% of puzzles in class
Correctly answered 50–75% of puzzles in class
Correctly answered >75% of puzzles in class
Percentage in category out of total
(21%)
(32%)
(41%)
(6%)

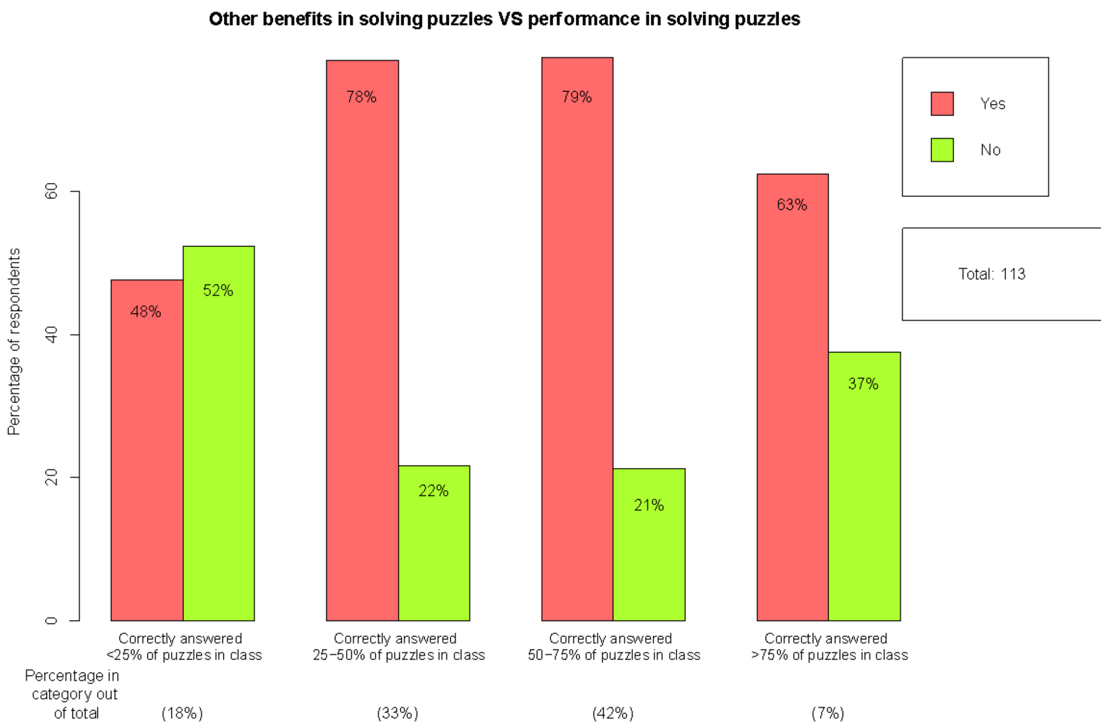


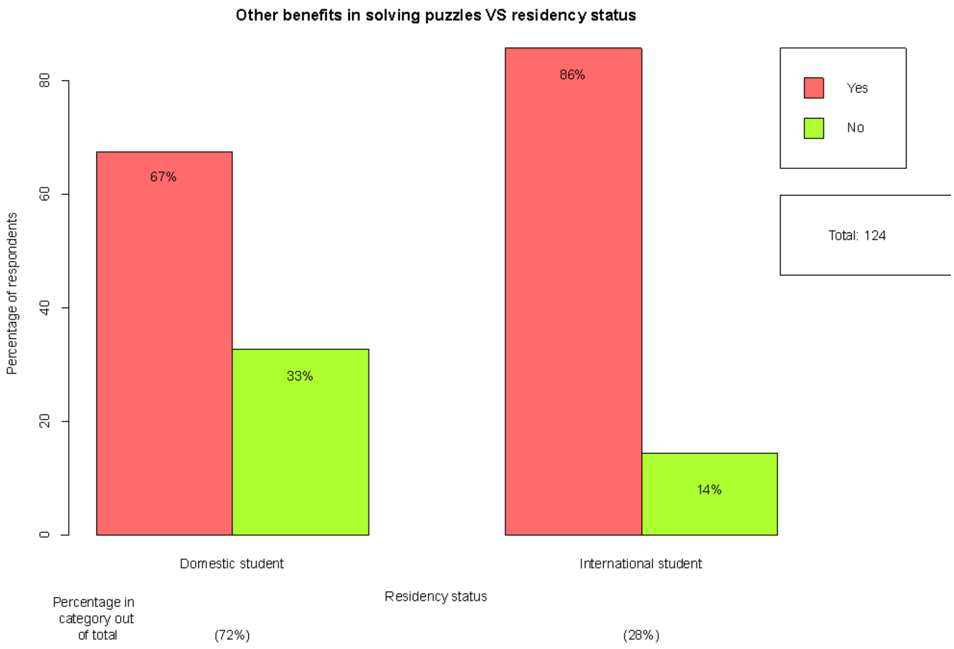
Enhancing generic thinking skills VS grade in pre−requisite course
Percentage of respondents
0
20
40
60
80
84%
16%
96%
4%
84%
16%
Yes
No
Total: 121
A − band grade
B − band grade
C − band grade
Percentage in category out of total
Grade in pre−requisite course
(42%)
(42%)
(16%)



Enhancing generic thinking skills VS gender
Percentage of respondents
0
20
40
60
80
91%
9%
89%
11%
Yes
No
Total: 128
Male
Female
Percentage in category out of total
Gender
(59%)
(41%)


Comments on other benefits from solving puzzles
Percentagr of respondents
0
20
40
60
80
100
13%
87%
100%
7%
93%
63%
37%
80%
20%
100%
100%
Yes (82%)
No (18%)
Total: 76
Improves thinking/
problem solving skills
Applicable in
real life
Not applicable/
waste of time
Not listening
in class
Prefer as
group exercise
None
Percentage in
category out
of total
(30%)
(30%)
(18%)
(11%)
(7%)
(1%)
(3%)


Other benefits in solving puzzles VS performance in solving puzzles
Percentage of respondents
0
20
40
60
48%
52%
78%
22%
79%
21%
63%
37%
Yes
No
Total: 113
Correctly answered
<25% of puzzles in class
Correctly answered
25–50% of puzzles in class
Correctly answered
50–75% of puzzles in class
Correctly answered
>75% of puzzles in class
Percentage in
category out
of total
(18%)
(33%)
(42%)
(7%)



Other benefits in solving puzzles VS residency status
Percentage of respondents
0
20
40
60
80
67%
33%
86%
14%
Yes
No
Total: 124
Domestic student
International student
Residency status
Percentage in category out of total
(72%)
(28%)

Appendix 3 Interview Questions

1. How would you describe yourself in relation to mathematics?
2. Can solving puzzles enhance your creativity? If so, in what way?
3. Is there any connection between the ability to solve puzzles and innovative thinking? Can you give any examples?
4. Do you use any specific strategy/plan/approach when you try to solve a puzzle? If so, what is it?
5. How would you describe the type of thinking you use when you are solving a puzzle? Is it the same as you use to solve a routine question?
6. Can you use puzzle solving skills in other areas of life? If so, in what way? Can you give examples?
7. Would you like to see puzzles in other courses? Why?
8. Do you have any other comments on using puzzles as a pedagogical strategy?
9. Can you describe how do you feel when solving puzzles? Did you enjoy solving the puzzles? Why? Do you feel anxious at any moment when solving puzzles? If you do, how do you handle it?
10. Do you think solving the puzzles helped your mathematics? If so, in what way?

    Does solving puzzles motivate you to study more mathematics?

11. How confident do you feel about solving puzzles?
12. Do you have any ideas on how to make puzzles a more effective resource in mathematics?
13. What features do you think make a good puzzle in mathematics?

Approved by the UoA Human Participants Ethics Committee on 14/10/16 for 3 years. Ref. # 018102