PO Box 3237
Wellington, New Zealand
Email: tlri@nzcer.org.nz
Website: www.tlri.org.nz

Full Proposal cover sheet (2017)

Title of proposal:	Investigating the Impact of Non-routine Problem Solving on Creativity, Engagement and Intuition of STEM Tertiary Students			
Research focus: (indicate which option)			Tertiary	

Principal investigator details: (up to two)		
Name	Associate Professor Sergiy Klymchuk, AUT	Emeritus Professor Mike Thomas, University of Auckland
Email address (for receiving notification of decision)	sergiy.klymchuk@aut.ac.nz	moj.thomas@auckland.ac.nz
Phone	09-921 9999 ext. 8431	021-02356189

Institution/organisation details:	
Name of institution/organisation	Auckland University of Technology (AUT)

Brief description of project: (up to 100 words)

This project aims to investigate the creative thinking skills and engagement of STEM (science, technology, engineering, mathematics) students as a result of solving non-routine problems during their learning. The participants comprise five groups of students from four diverse tertiary institutions who are studying different STEM subjects. Their learning will be enhanced by the addition of non-routine problem solving activities. Learners' creativity, engagement and intuition will be analysed to evaluate the effect of this innovative practice. We anticipate that wide implementation of this learning enhancement would improve the employability of STEM students since innovative and creative thinking is a workplace requirement.

This application is for: (please indicate)		
	Type I - Category B (up to $200K) (Max. $100K in any one year)	2018: $98,377 2019: $99,828 Total: $198,205
N.B. Figures are exclusive of GST		

2. Title of the Research Project

Investigating the Impact of Non-routine Problem Solving on Creativity, Engagement and Intuition of STEM Tertiary Students

3. Description of Proposed Project and its Context

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). Low engagement and retention rates in STEM subjects contribute to the shortage of STEM graduates, producing a negative impact on the New Zealand economy. A significant number of STEM tertiary 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 specific terms to describe this, such as *emotional* *disengagement* and *academic disinterest* (Blondal & Adalbjarnardottir, 2012). Many teachers/lecturers would agree that interesting non-routine problems, including puzzles, paradoxes and sophisms can engage students' emotions, creativity and curiosity and also enhance their conceptual understanding, critical thinking skills, problem-solving strategies and lateral thinking "outside the box". With this mind, the proposed project seeks to implement and evaluate a pedagogical intervention aimed at enhancing learner engagement in STEM courses and increasing their creativity more generally. A non-routine problem is one for which the students do not have a ready-made method of solution that they can apply to solve it, but which is within the scope of their knowledge base. A typical non-routine problem requires some creativity and originality to solve it. 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 et al., 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, 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. Puzzles, paradoxes and sophisms have many common features. Among them are: simplicity (often deceptive); an entertainment flavour; and a surprise counterintuitive answer or an unexpected solution. For convenience, in this project, we will refer to puzzles, paradoxes and sophisms as puzzles.

Apart from the widespread belief that non-routine problems and puzzles increase motivation there are other benefits to learners. Solving them can be linked to the development of professional skills. In the case of engineering students, Parhami (2008) argues: "Many engineering problems are puzzlelike. Pieces of the puzzle are provided to engineers in the form of user/customer requirements, technological constraints, professional or industrial codes, and market realities. The engineer must then craft a product or process that either meets all these (often conflicting) demands or else provides partial solutions, with clear justification of the tradeoffs made when meeting all of the specifications is not possible…Puzzling problems are, of course, plentiful in the research arena, regardless of the discipline." (p. 263).

Often students learn STEM subjects in a procedural way as a set of techniques and instructions relevant to the content of a specific course. Fisher (2001) claims: ". . . though many teachers would claim to teach their students `how to think', most would say that they do this indirectly or implicitly in the course of teaching the content which belongs to their special subject. Increasingly, educators have come to doubt the effectiveness of teaching `thinking skills' in this way, because most students simply do not pick up the thinking skills in question." However, many high-tech companies require good *generic* problem-solving and thinking skills from their job candidates in addition to the knowledge and capability of applying certain techniques. To select best of the best companies use puzzles at their job interviews. They believe that the ability to solve puzzles relates to the creative thinking needed for solving innovative real life problems. 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 Mātauranga (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 mātauranga Māori: "the weaving of knowledge across different domains, in a cross-disciplinary and cross-cultural style" (p. 16).

In a typical STEM curriculum there is no space for a course on generic thinking skills. Lecturers hope that their students develop and enhance their generic thinking skills by solving specific problems from the course. However, students often have difficulties in applying their problem solving skills outside the particular context, content or subject they have learnt in class. One possible reason might be that students are exposed mostly to routine problems in their assignments and tests that require an application of a known procedure or technique. In his classic book on problem solving, Schoenfeld (1985) found that university students tend to spend little time on planning solutions. Instead, they quickly jump into "doing mathematics" and writing it down. For a routine problem (Schoenfeld called it an exercise) this strategy might work. But this is not the case with non-routine problems. Selden et al. (2000) investigated students' difficulties in calculus and found that while solving non-routine problems above-average university engineering students often used sophisticated algebraic methods that lead them nowhere (76% failure rate) instead of accessing the knowledge from calculus they possessed. An even worse failure rate was reported in another study on engineering university students' difficulties in solving a problem from calculus that had a "non-routine" wording (2010). About 95% of the students (187 out of 197) failed to solve an application problem on a test mainly due to what was, for them, an unusual wording of the problem: instead of the more common formulation "find the velocity that minimizes the total cost of a journey" the question was "show that to minimize the total cost of a journey the truck should run approximately 28 km/h". Many students simply did not know into what formula they should substitute the *given* answer 28.

In the proposed project we will use the Puzzle-Based Learning concept introduced by Michalewicz and Michalewicz (2008). The authors indicated the following criteria for a puzzle: independence (domain free); generality; simplicity; eureka factor; entertainment factor. The relationship of the Puzzle-Based Learning with the well-established Problem-Based Learning (Bransford et al., 1986) and Project-Based Learning (Blumenfeld et al., 1991) concepts is illustrated in Figure 1:

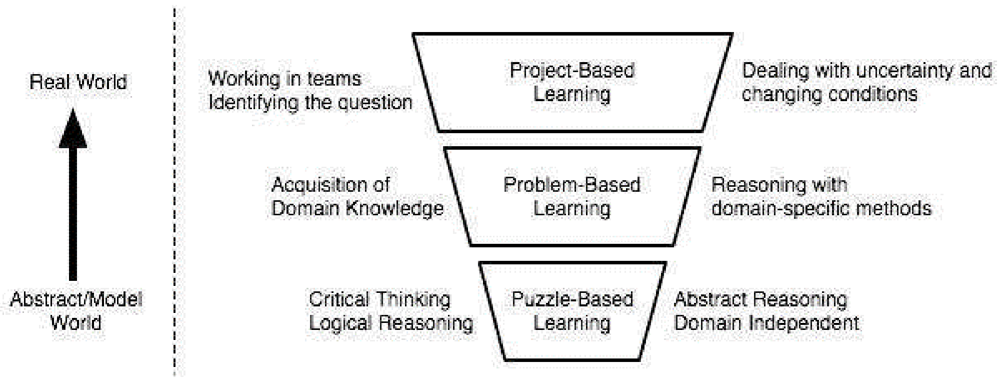

Figure 1. Relationship between different PBL concepts (Falkner et al., 2012a).

There are good discussions of the relationships between the three concepts in (Falkner et al., 2012a; Falkner et al., 2010) and between Problem-Based Learning and Puzzle-Based Learning in (Thomas, 2013).

Falkner et al. (2010) claim: "The puzzle-based learning approach aims to encourage engineering and computer science students to think about how they frame and solve problems not encountered at the end of some textbook chapter. Our goal is to motivate students while increasing their mathematical awareness and problem-solving skills by discussing a variety of puzzles and their solution strategies." (p. 21). What was new was the development of a formal academic course for university students devoted to the Puzzle-Based Learning. In recent years, some universities in the USA, Australia and Europe have introduced formal academic courses or seminars for their first-year STEM students based on the Puzzle-Based Learning approach as a pedagogical strategy. At some universities those courses/seminars are even compulsory. The triggers were the publication of the books (Michalewicz & Michalewicz, 2008; Meyer et al., 2014) and a series of conference presentations, journal articles, promotional workshops and seminars around the world by the enthusiastic authors of the two books. Preliminary feedback from those courses is promising. Falkner et al. (2012b) 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, as we can see when students apply these skills in their algorithmic development, their identification of test cases and their improved understanding of insufficient problem specification." (p. 267). A similar positive impact for learners of engineering mathematics is reported in (Thomas, 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. In this aspect the procedure for solving puzzles is similar to model development and solution, and is an essential part of engineering. As far as active or reflective processing of information is concerned, the best puzzles for teaching engineers should be amenable to both approaches, although the 'eureka' moment will usually arise from reflection. If puzzles are introduced as group work, this can appeal to students with an active learning style who appreciate working with others. 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). Parhami (2008) has successfully run Puzzle-Based Learning seminars for computer engineering students with the aim to improve their retention rate by increasing their motivation and engagement: "We maintain that attracting students to computer science and engineering programmes, while necessary and helpful, counteracts only one aspect of the problem. Retaining and motivating students once they have chosen a computing major are other key aspects. A greater retention rate will improve the quantity and quality of our graduates much more effectively than simply admitting more students, as the latter approach would require digging deeper into the applicant pool" (p. 262).

The proposed project is based on a related 2015 pilot project at AUT supported by the Centre for Learning and Teaching and another joint pilot project of AUT and University of Auckland "Enhancing Generic Thinking Skills of Tertiary STEM Students through Puzzle-Based Learning: Students' Perspectives" in 2016-2017 supported by a $10,000 grant from the Northern Hub Regional Fund of Ako Aotearoa National Centre for Tertiary Teaching Excellence (projects' leader Sergiy Klymchuk). Both pilot projects investigated students' *attitudes* towards and *perceived values* of the regular use of puzzles as a pedagogical strategy in STEM courses. The findings from both pilot projects revealed that the vast majority of the participants (92-98%) believed that solving puzzles enhanced their problem solving skills and generic thinking skills. The majority of the participants' favourable comments (around 80%) were related to creativity. Commenting on different aspects of creativity the students expressed their *perceptions* using their own words.

The focus of the proposed project is to analyse the impact of non-routine problems and puzzles on enhancing student creativity, engagement and intuition. Creativity in this context is understood as what Leikin called 'relative creativity' (2009, 2013) or what Sriraman (2017) called "ordinary, or everyday creativity (or little c)" as opposed to "extraordinary creativity (or big C) that refers to exceptional knowledge or products that change our perception of the world." In the proposed project, Guilford's model of creativity (1959) based on divergent thinking will be used as a theoretical framework with some links to Haylock's investigative model of creativity (1987, 1997) based on overcoming fixations. The Torrance Tests of Creative Thinking (Torrance, 1963) based on Guilford's model will be used to measure creativity. In the proposed project we will measure engagement (behavioural, emotional, and cognitive) using an adapted version of the model introduced by Fredricks, Blumenfeld, and Paris (2004).

By their nature most puzzles have surprise and counterintuitive answers. Therefore, while solving puzzles it is important for learners to control their intuition to employ standard ideas or approaches that may lead to erroneous solutions. According to Gilmore et al. (2015) inhibition is "suppressing distracting information and unwanted responses". In the proposed project, the process of inhibiting intuitive thinking will be investigated using the dual-process theory of reasoning (reviewed in Evans, 2003). According to this model, Type 2 thinking (analytic, slow, sequential, controlled, logical) in some cases needs to be used to inhibit Type 1 thinking (intuitive, heuristic, instinctive, rapid, automatic). A good overview of inhibiting intuition in this manner is given in (Thomas, 2015).

As an overall theoretical framework for the project we propose a novel application of Schoenfeld's (2010) theoretical framework for goal-oriented decision making. Although this framework was developed for teaching, initial discussions by one of the PIs with Alan Schoenfeld indicate its applicability to student learning as well. The framework describes how the Resources, Orientations and Goals (ROG) that individuals call upon are linked to in-the-moment decisions made in learning. Of course, the quality of the decision making influences how successful a student will be in their goal of solving problems. In the theory, the decisions a student makes when solving problems are a result of their problem solving goals. In turn these goals, and their prioritisation, are shaped by an individual's orientations, "…an inclusive term encompassing a group of related terms such as dispositions, beliefs, values, tastes and preferences." (Schoenfeld, 2010, p. 29). Once the student has oriented himself to a non-routine problem and set immediate goals for the current situation, s/he then has to decide on what direction to take to achieve the goals. To do this they call on the available resources, primarily his/her knowledge, in order to meet them.

Thus non-routine problem solving decision-making involves complex interactions of an individual's ROG for a given situation. The metacognitive processes of self-monitoring and self-regulation are also important in deciding how well things are progressing (Schoenfeld, 2010). Orientations are crucial, since "What people perceive, how they interpret it, and how they prioritize the ways they might respond to what they see are all shaped in fundamental ways by their orientations." (Schoenfeld, 2010, p. 44). Thus we hypothesise that during non-routine problem solving learners' creativity and engagement and their ability to regulate intuition will be closely related to their ROGs.

The main research questions of our project are:

- Does the use of non-routine problems enhance participants' engagement and learning? Specifically, is the integration of non-routine problems and Puzzle-Based Learning associated with changes in participants' engagement (emotional, cognitive, and behavioural) in lecture and/or their ability to inhibit intuitive thinking and exhibit creative thinking?
- To what extent are any effects moderated by individual differences such as demographic characteristics, ROGs or prior ability? For example, does the response to intervention vary significantly based on learners' gender, age, ethnicity, or the ability to think creatively as measured at baseline?
- Finally, how do learners feel about solving non-routine problems and the integration of Puzzle-Based Learning in their lectures? Do they think the intervention was enjoyable and effective? What did they like the most and least? What do they think could be changed to make it more engaging and effective?

We believe that answers to these questions will contribute to the knowledge of thinking processes that involve creativity and innovation, particularly among STEM tertiary students. Dissemination and implementation of Puzzle-Based Learning in STEM subjects as a pedagogical strategy can potentially increase the retention rate in those subjects that would be beneficial for the New Zealand knowledge economy.

The proposed project is related to or partially built on the following five previous TLRI projects:

- Understanding and enhancing learning communities in tertiary education in science and engineering (2005-2006), Centre for Science and Technology Education Research, University of Waikato.
- Learning environments and student engagement with their learning in tertiary settings (2008-2009), College of Education, Massey University.
- The transition from secondary to tertiary education in mathematics (2008-2009), The University of Auckland and AUT.
- Unlocking student learning: The impact of Teaching and Learning Enhancement Initiatives on first-year university students (2006-2008), Massey University.
- Learning the work of ambitious mathematics teaching (2012-2014), Massey University and Victoria University of Wellington.

The proposed project is not related to the ongoing TLRI project "Making mathematical thinking visible" (2016-2017 by the University of Auckland) that deals with mathematical modelling activities and addresses completely different research questions.

4. Research Design and Methodology

As detailed above, the proposed project seeks to address several distinct research questions concerning not only the effectiveness of an intervention on learner engagement and creativity but also learners' attitudes toward non-routine problems and the intervention itself. In order to address these distinct questions in the best manner, the proposed study will use a mixed-method research design; specifically, a sequential design that employs both quantitative and qualitative research methods. As illustrated in Figure 2, this type of research design unfolds over time in a series of phase, each with its own set of purposes, data types, analyses and sources.

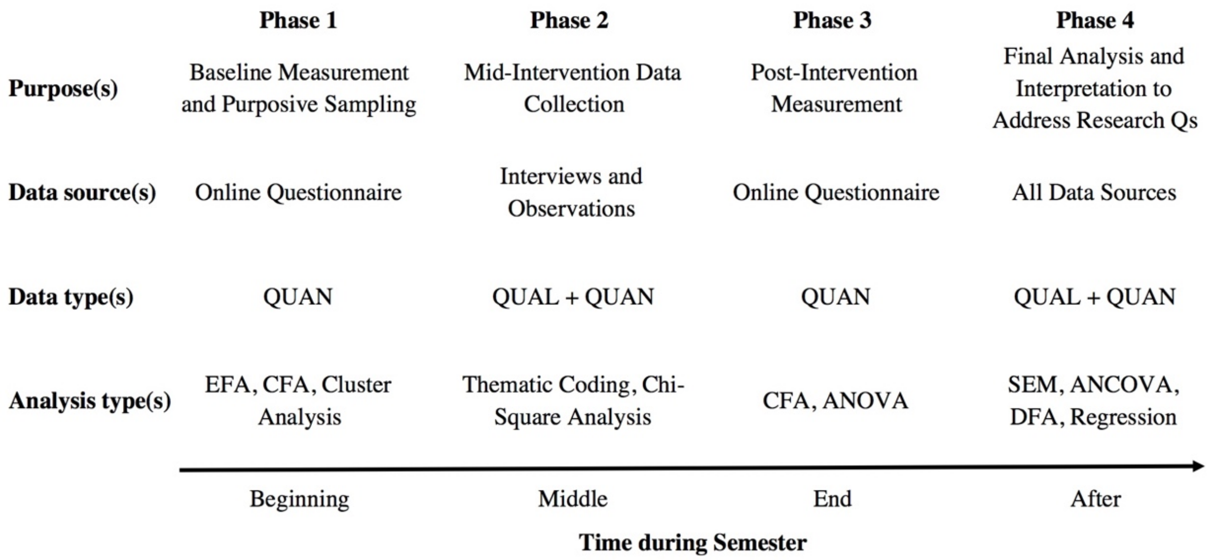

Figure 2. A Sequential, Four-Phase Mixed-Methods Research Design.

Phase One: Completion of Baseline Measures and Creation of Sampling Frame

Selected lecturers of STEM subjects in five groups from four tertiary institutions will be using non-routine problems and puzzles on a *regular* basis (2-3 per week during the semester) in their teaching. We expect that 400-500 students will be exposed to this pedagogical strategy. The proposed project will begin during the first two weeks of the semester. During this time, all enrolled STEM students from five selected groups in four tertiary institutions will be informed of the study and offered an opportunity to participate in it. Those that consent to do so will be asked to complete an online questionnaire. This questionnaire will comprise numerous measures including self-report scales of engagement (emotional, cognitive, and behavioural) and inhibited intuition related to non-routine problem-solving as well as the Torrance Tests of Creative Thinking. These data will serve two purposes: firstly, to create a sampling frame of potential participants for the interviews conducted in Phase Two (detailed next); and, secondly, as baseline data in assessment of intervention effects on learner engagement and creative thinking (see Phases Three and Four).

Phase Two: Mid-Intervention Data Collection—Interviews and Observations

During the semester two types of data collection activity will be undertaken concurrently. First, as alluded to above, the questionnaire data gathered in Phase One will be used to create a sampling frame from which to select potential interview participants. Specifically, cluster analyses will be used to classify participants into groups according to their responses on the survey scales and performance on the Torrance Tests. Table 1 below offers an example of the type of sampling frame that would be derived from these analyses. As indicated below, we anticipate individually interviewing 10 students from five discrete groups (total N=50) based on a 3 x 3 configuration of learner engagement and creativity at baseline. Doing so allows the creation of a *purposive sample*—in this case, a mix of learners representing all "corners" (i.e., those with mean scores in the highest and/or lowest tertile on engagement and/or creativity) and the middle (i.e., those with mean scores on both engagement and creativity).

Table 1.

Sampling Frame for Interview Selections

	Tertile of Creativity (Torrance Test Score)		
Tertile of Engagement	Low	Middle	High
Low	10	--	10
Middle	--	10	--
High	10	--	10

In selecting the 10 learners from each group to interview, we will also ensure that each is representative in terms of demographic characteristics such as learner sex, age, and ethnicity. Those selected will be contacted via email to schedule a mutually convenient time to meet. The interview will be approximately 45 minutes in duration and guided by a semi-structured protocol of questions. Specifically, the protocol will include prompts and questions designed to address the third research question concerning learners' feelings about solving non-routine problems and the integration of Puzzle-Based Learning (PzBL) in their lectures. For example, participants' will be asked the following questions: *Can you describe how you feel when solving puzzles? Did you enjoy solving the puzzles? Why? Do you feel anxious at any time when solving puzzles? If you do, how do you handle it? 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? What do think of the way PzBL is used in this course? Do you think it's useful or helpful in any way? What do you like the most and least about it? What do you think could be changed to make it more engaging or effective?* We will also observe some students actually solving non-routine problems and puzzles and telling us what they are thinking and feeling. At the end of the interview, students will be offered a gift voucher as a token of appreciation for their participation.

Second, classroom observations will be conducted to assess learner behavioural engagement during PzBL. Specifically, each course will be observed for 30 minutes on three occasions during weeks 3 through 12. During this time an observational protocol will be used to register on- and off-task behaviour among learners every two minutes by at least two researchers. The 30-minute interval to be observed will be selected into the 10-minutes of PzBL; ideally, the middle 10-minutes, so engagements rate during PzBL can be systematically compared to learner engagement in the time preceding and following the intervention. In the larger courses (N > 100), cross-tabulation with Chi-square analysis will be conducted to test for differences in engagement (on- vs. off-task behaviour) across the three intervals. The results of these analyses will be important in addressing part of the first research question.

Phase Three: Post-Intervention Measurement

At the end of the semester, all participants will be emailed again and asked to complete a final questionnaire. The questionnaire will mainly comprise the same measures (or their alternative forms) used on the baseline questionnaire. Ultimately (in Phase 4) these data will be combined with data from Phases One and Two to address our three research questions. During this Phase, the data collected will be subjected to the same rigorous analyses conducted on the baseline measures; namely, the use confirmatory factor analysis to validate the factor structure of the measurement models and to test for measurement invariance across time. More specifically, two measurement models will be tested: the three-factor model for learner engagement (Fredricks, Blumenfeld, & Alison, 2004) and the single-factor model of inhibited intuition (Thomas, 2015).

With respect to the measurement of creativity, we have indicated the Torrance Tests for Creativity (Torrance, 1972) as a possibility. With several decades of research behind it, it is one of the most comprehensive and widely used objective measures of creativity (for a review, see Cramond, Matthews-Morgan, Bandalos, & Zuo, 2005). However, it is a costly measure to use. Accordingly, we are currently investigating other objective measures of creativity, such as the Remote Associates Test (Lee, Huggins & Therriault, 2014) which comprises only 30 items and can be administered online. Finally, we are also considering the use of subjective, self-report measures of creativity, such as "Consequences" Test (Furnham, Crump, Batey, & Chamorro-Premuzic, 2009). This measure is focused on the measurement of divergent thinking, one of the types of creativity in which the proposed project is most interested. Regardless, where applicable, CFA and/or other analytic techniques will be employed to ensure the validity and reliability of the measure(s) ultimately selected and used in this study.

Phase Four: Final Analyses and Interpretation to Address Research Questions

After the semester, all data collected will be compiled into a single dataset and de-identified (i.e., all unique identifiers, such as names, will be removed to anonymise the data). Once "cleaned," we anticipate spending approximately three months analysing the data to address the three research questions being investigated. The remainder of this section details the specific types of analyses that will be employed for each question.

The first research question asks if the intervention is effective: *Does the integration of puzzle-based learning associated with changes in participants' engagement (emotional, cognitive, and behavioural) in lecture and/or their ability to inhibit intuitive thinking and exhibit creative thinking?* Given we are using a quasi-experimental design (pretest-posttest with no comparison group), repeated measures analysis of variance (ANOVA) will be used to test for individual changes in engagement, inhibited intuition, and creativity across time.

The second research question seeks to determine the extent any significant changes are moderated by individual differences such as demographic characteristics, ROGs or prior ability: *Does the response to intervention vary significantly based on learners' gender, age, ethnicity, or the ability to think creatively as measured at baseline?* Once again, a repeated measures ANOVA can be employed to test for such difference by adding these categorical data as between-subject factors in the model.

Finally, the third research question inquires about learners' feelings about solving non-routine problems and their perceptions of puzzled-based learning they experienced: *Do they think the intervention was enjoyable and effective? What did they like the most and least? What do they think could be changed to make it more engaging and effective?* These questions will be answered using the qualitative interview data collected, transcribed, and coded during Phase Two. Specifically, a thematic analysis approach (see Braun & Clarke, 2006) will be used for identifying, analysing, and reporting the themes and subthemes that emerged from 50 interviews conducted.

Specific Ethical Issues

This research project uses a quasi-experimental design, which removes the issue of disadvantaging a group of students as we do not have a comparison group. In particular, all students will be exposed to the same teaching and learning methods. There are several ethical issues that arise in this project – primarily concerning the acts of collecting and analysing the data.

We will start collecting the data during the first two weeks of Semester 2 2018. During this time, all enrolled STEM students from five selected groups in four tertiary institutions will be informed of the study and offered an opportunity to participate in it. Those that consent to do so will be asked to complete an online questionnaire. At this time students will be notified that they can withdraw from the study at any time. Questionnaires will be completed online and the data collected will be only accessed by researchers who are not involved in teaching any of the courses. Jason Stevens (University of Auckland - UoA, Faculty of Education – not teaching any of the courses) will take responsibility for the progression to Phase Two by performing cluster analysis and creating a sampling frame. He will also contact the chosen students who volunteered to be interviewed.

Interviews will be transcribed and coded to de-identify the students. The interviews will be conducted by researchers who are not affiliated in any manner with the courses. For example: Tanya Evans (from UoA) will interview students from AUT and Sergiy Klymchuk (from AUT) will interview students from UoA. Similarly, lecture observations will be conducted by researchers who are not affiliated with the students: for example Jason Stevens (UoA, Faculty of Education) will be conducting lecture observations of MATHS 208 students.

The main analysis of the data will take place after all grades for the courses are finalised. After the semester, all data will be compiled into a single, de-identified dataset, which means that all unique identifiers, such as names, will have been removed to anonymise the data. The entire research team will only have access to the data after this is complete.

Finally, we would like to note that we have considered and dealt with similar ethical issues as part of our recent small pilot project (joint between AUT and University of Auckland titled “Enhancing Generic Thinking Skills of Tertiary STEM Students through Puzzle-Based Learning: Students’ Perspectives”, 2016-2017 supported by the Northern Hub Regional Fund of Ako Aotearoa National Centre for Tertiary Teaching Excellence). As part of this project we were granted ethics approval by the University of Auckland Human Participants Ethics Committee on 14/10/16 for 3 years (ref.# 018102).

Project Team

The project team consists of 10 experienced academic staff. Their affiliations, roles and subject areas in the project are below:

1. Associate Professor of Mathematics Sergiy Klymchuk, AUT, Principal Investigator, Researcher, mathematics and engineering education.
2. Emeritus Professor of Mathematics Education Mike Thomas, University of Auckland, Principal Investigator, Researcher, mathematics education.
3. Associate Professor of Education Jason Stephens, University of Auckland, Associate Investigator, Researcher, education.
4. Dr Julia Novak, University of Auckland, Associate Investigator, Researcher, science and mathematics education.
5. Dr Tanya Evans, University of Auckland, Associate Investigator, Researcher, mathematics education.

6. Professor Sergei Gulyaev, AUT, Practitioner, physics and astronomy education.
7. Dr William Liu, AUT, Practitioner, computer science education.
8. Dr Jordan Alexander, AUT, Practitioner, physics and astronomy education.
9. Dr Andrew Zaliwski, Whitireia New Zealand, Practitioner, computer science education.
10. Priscilla Murphy, MIT, Practitioner, mathematics and engineering education.

The team has 250+ years combined experience in teaching STEM subjects in 10 countries. All team members have experience and/or interest in STEM education research covering the following STEM subjects: mathematics, engineering, physics, astronomy, computer science. Nine team members are either members or associate members of the AUT STEM Tertiary Education Centre (STEM-TEC). The members' page of the STEM-TEC website is: https://stemtec.aut.ac.nz/members. Our partnership has emerged over the past 12 years, resulting in:

- joint publications by Mike Thomas, Sergiy Klymchuk and Priscilla Murphy; Sergei Gulyaev and Sergiy Klymchuk; Julia Novak and Tanya Evans; Sergei Gulyaev and Jordan Alexander;
- events organised by the AUT STEM-TEC Centre and Mathematics Education Unit of the University of Auckland, including seminars, symposiums, and workshops; and
- two previous national projects: the 2008-2009 TLRI project on the transition from secondary to tertiary education in mathematics (Mike Thomas and Sergiy Klymchuk were principal investigators and Priscilla Murphy a team member) and 2016-2017 Ako Aotearoa Regional Hub Project Fund pilot project on enhancing generic thinking skills of tertiary STEM students through Puzzle-Based Learning (Sergiy Klymchuk is the leader and Mike Thomas, Tanya Evans and Sergei Gulyaev are team members).

This history of productive collaboration together is rooted in part in the rich mix of expertise represented among the team members. This rich mix includes experts in numerous subject disciplines and/or education in those disciplines (for example, mathematics and mathematics education; astronomy and astronomy education; computer science and computer science education). These differences notwithstanding, we all have passion for using non-routine, thought provoking activities in teaching STEM subjects. We consider it important that all team members have opportunities to enhance their skills in some area. Hence, we will make sure that the five members with a practitioner role Sergei Gulyaev, William Liu, Jordan Alexander, Andrew Zaliwski, Priscilla Murthy (who are excellent in their own STEM discipline but with little or no experience in their STEM *subject education* discipline) will learn from the five researchers in STEM education or education Mike Thomas, Sergiy Klymchuk, Jason Stephens, Julia Novak, Tanya Evans via joint activities of posing research questions, selecting theoretical frameworks, research design, and data collection and analysis. We will also provide opportunities for building the research capability and expertise of less experienced researchers. In particular, Professor Mike Thomas and Associate Professors Sergiy Klymchuk and Jason Stephens will be mentoring Dr Julia Novak and Dr Tanya Evans. One way of developing research capability of practitioners is the use of reflective practices based on the Resources-Orientations-Goals (ROG) framework (Shoenfeld, 2010). In turn, the researchers in the team will be guided by the practitioners to reflect on, and hence improve, their teaching practice. In addition to mentoring by researchers and assisting them with their teaching practice, the practitioners are themselves expected to reflect on how (pedagogy) and why (orientation) STEM subjects are taught and learned. These questions will generate some reflections and insights for all on effective teaching and learning: How can STEM lecturers promote creative/intuitive thinking in Puzzle–Based Learning (PzBL)? What are some personal factors that determine student engagement in learning STEM subjects? How can STEM lecturers promote inclusive education to meet the diverse needs of learners? To what extent do lecturers require professional development to teach PzBL? What are some surprising moments of teaching PzBL? What are some expected moments of teaching PzBL and why? In preparing this proposal we have had numerous face-to-face discussions and e-mail communications and five formal team meetings at the AUT STEM Tertiary Education Centre. We were all involved in writing the proposal with the five researchers leading and mentoring the five practitioners in discussions on research questions, theoretical frameworks, research design and methodology. The five practitioners will be more involved in the data collection and analysis – again with the help and guidance from the five researchers. We expect that all team members will be involved with writing the final report and disseminating findings via publications and presentations of seminars and workshops around New Zealand. We formally confirmed our partnership by signing in August three Memorandums of Understanding between the leading organization (AUT) and the other tertiary institutions involved in the project: the University of Auckland, Manukau Institute of Technology and Whitireia New Zealand. For quality assurance of our project we will have an advisory committee of three outstanding experts in the fields of mathematics and mathematics education who have kindly agreed to act as external reviewers and critical friends at strategic points in the project. A brief introduction to the members of our advisory committee is below:

1. Sir Vaughan Jones KNZM FRS FRSNZ FAA, is a New Zealand mathematician who was awarded a Fields Medal in 1990 - the Nobel prize equivalent for mathematics. Jones is currently at Vanderbilt University as Stevenson Distinguished Professor of mathematics. He remains Professor Emeritus at University of California, Berkeley where he has been on the faculty since 1985 and is a Distinguished Alumni Professor at the University of Auckland.

2. Professor Merrilyn Goos, the University of Queensland, is Vice-President of the International Commission for Mathematical Instruction (the leading organisation in mathematics education in the world), a former President of the Mathematics Education Research Group of Australasia (MERGA) and Editor-in-Chief of Educational Studies in Mathematics, the leading journal in the field. From Oct 2017 she will be Professor of STEM Education and Director of the National Centre for STEM Education, University of Limerick, Ireland.

3. Professor Glenda Anthony, Massey University, Professor of mathematics education, Co-Director of the Centre for Research in Mathematics Education, Panel Member of the TEC PBRF Education panel.

5. Practice Value

By analysing data from our project we aim to establish evidence of enhanced creative thinking skills of STEM tertiary students as a result of solving non-routine problems as part of their learning. In the case of positive outcomes of the project we will be able to consolidate knowledge which will allow us to recommend the incorporation of our innovative practice in teaching and learning of STEM subjects. The regular use of non-routine problems can be incorporated into existing courses on different scales, ranging from as little as 5 minute mid-lecture 'breaks' once a week to designing a whole course utilising non-routine problems as a means of learning. We seek to establish evidence that even a relatively small change in teaching STEM students will lead to improvements in the outcomes for learners – in particular improvements in their creative thinking skills and retention. This may ultimately lead to improved employment opportunities as our tertiary graduates are facing today’s world of uncertainties of future professions, which are influenced by the advances of Artificial Intelligence and fast-change technological environments. The tertiary education sector should place a greater emphasis on supplementing content knowledge with skills that will allow graduates to be adaptable in the workforce of the future.

In the case of positive outcomes of the project our findings will allow for a straightforward dissemination of the evidence-based innovative practice that has the potential to build the capability of all STEM teachers who choose to add non-routine problems into their teaching and learning practices. They will be provided with resources that they can use in their teaching and learning practices, in particular those developed or collected by the team members of this project. The resources will be added to the Resources Page on the website of AUT STEM Tertiary Education Centre (STEM-TEC). We will also create a separate page on the same website devoted to the project and will update it regularly. Dissemination channels will include at least 8 workshops or seminars for practitioners – teachers and lecturers of STEM subjects at tertiary institutions around New Zealand – spread over two years. We also plan to publish an article or two in *SET* for practitioners. We plan at least 2 presentations per year at relevant national and international conferences such as the annual international conference of the International Group for the Psychology of Mathematics Education (IGPME), the annual international conference Mathematics Education Research Group of Australasia (MERGA); the annual international STEM education conference; the biennial conference of the New Zealand Association of Mathematics Teachers (NZAMT); an annual conference of Auckland Mathematical Association (AMA) and the annual Tertiary Education Research New Zealand conference (TERNZ). We also plan to submit at least 2 publications per year to leading international research journals on tertiary teaching and learning and STEM education, such as the International Journal of Mathematical Education in Science and Technology (iJMEST), the International Journal of Research in Undergraduate Mathematics Education (IJRUME) and the International Journal of STEM Education. This project will also feed into the ongoing three year project funded by Ako Aotearoa (PI Professor Susan Geertshuis, Director of Learning and Teaching at the Business School, University of Auckland), which investigates 'Embedding employability in the curriculum' by linking learner enhancement of creative and innovative thinking with their increased employability. At the time of writing two members of our team (Dr Tanya Evans and Associate Professor Sergiy Klymchuk) have been interviewed for the above project, linking it to our project.

6. Project Timetable

Starting date of the project – 1 January 2018
Milestone 1 – Finalising all measures and procedures needed for data collection including questionnaire and interview questions – by March 2018
Milestone 2 – Securing ethics approval – by May 2018
Milestone 3 – Data collection in various groups at four tertiary institutions – July-November 2018
Milestone 4 – Completed data analysis – by April 2019
Milestone 5 – Dissemination (seminar/conference presentations, writing journal articles) – May-October 2019
Milestone 6 – Writing the report – November-December 2019
Finishing date of the project – 31 December 2019

7. Appendix: Project Team Biographies (Key People)

Auckland University of Technology
ACADEMIC CV

NAME: **Sergiy Klymchuk, MSc, PhD, FIMA, MRSNZ**
CURRENT POSITION: **Associate Professor**
DEPARTMENT: **Mathematical Sciences**
SCHOOL: **Engineering, Computer and Mathematical Sciences**
FACULTY: **Design and Creative Technologies**

Educational Qualifications
1980 Odessa National University, Ukraine, MSc, Applied Mathematics
1988 Odessa National University, Ukraine, PhD, Mathematics
2011 Fellow of the Institute of Mathematics and Its Applications (FIMA), UK

Employment
Auckland University of Technology: Lecturer 2000-2001; Senior Lecturer 2001-2005; Associate Professor 2005-present
University of Waikato: Mathematics Teacher (part-time) 1997-1999
Odessa National Economics University, Ukraine: Lecturer 1980-1989; Senior Lecturer 1989-1990; Associate Professor 1990-1996

Honorary Appointments
German Academic Exchange Services (DAAD) visiting Associate Professor, Wismar University of Applied Sciences, Technology, Business and Design, Germany 2006-2008

Academic Journal Appointments
International Journal "Mathematics Teaching-Research Journal Online", Co-chief Editor, 2015-present
International Journal "Teaching Mathematics and Its Applications" published by Oxford University Press, Associate Editor, 2012-present
Reviewer for 5 international journals ranked A or B by the Australian ERA: *Mathematics Education Research Journal; International Journal of Mathematical Education in Science and Technology; Journal of Mathematics Teacher Education; Australian and New Zealand Industrial and Applied Mathematics Journal; Teaching Mathematics and its Applications*

Professional Memberships in International Organisations
Member of the European Society for Engineering Education Mathematics Working Group (SEFI MWG) – since 2008;
Member of the International Group on Psychology in Mathematics Education (PME) – since 2001;
Member of the International Group on Improvements in Mathematics Education (CIEAEM) – since 1999;
Member of the International Community of Teachers of Mathematical Modelling and Applications (ICTMA) – since 1997

Selected External Research Grants
2016 Ako Aotearoa $10,000 (Leader); 2016 MBIE $28,500 (Co-leader); 2015 MBIE $21,850 (Co-leader); Ako Aotearoa 2012 $10,000 (Leader); TLRI 2008 $179,033 (Co-leader)

Selected Relevant Research Publications (from a total of 150+ refereed research outputs)

Klymchuk, S. (2017). Puzzle-Based Learning in engineering mathematics: Students' attitudes. *International Journal of Mathematical Education in Science and Technology*, *48*(7), 1106-1119.
Klymchuk, S. (2015). Provocative mathematics questions: Drawing attention to a lack of attention. *Teaching Mathematics and Its Applications*, *34*(2), 63-70.
Klymchuk, S. (2014). Experience with using counterexamples in an introductory calculus class. *International Journal of Mathematical Education in Science and Technology*, *45*(8), 1260-1265.
Klymchuk, S., & Staples, S. (2013). *Paradoxes and Sophisms in Calculus*. USA: Mathematical Association of America.
Klymchuk, S., & Kachapova, F. (2012). Paradoxes and counterexamples in teaching and learning of probability at university. *International Journal of Mathematical Education in Science and Technology*, *43*(6), 803-811.
Klymchuk, S., & Thomas, M. O. J. (2011). The influence of attention on mathematical knowledge of teachers and lecturers: A comparison. *International Journal of Mathematical Education in Science and Technology*, *42*(7), 1011-1020.
Klymchuk, S., Zverkova, T., Gruenwald, N., & Sauerbier, G. (2010). University students' difficulties in solving application problems in calculus: Student perspectives. *Mathematics Education Research Journal (MERJ)*, *22*(2), 81-91.
Klymchuk, S. (2010). *Counterexamples in Calculus*. Washington, USA: Mathematical Association of America.
Mason, J., & Klymchuk, S. (2009). *Using Counter-Examples in Calculus*. London, UK: Imperial College Press.

University of Auckland
ACADEMIC CV

NAME: **Prof M. O. J. Thomas BSc (Hons.), MSc, PhD, CMath, FIMA**
CURRENT POSITION: **Professor Emeritus**
DEPARTMENT: **Mathematics**
FACULTY: **Science**

Educational Qualifications
1972 University of Warwick, BSc (Hons.), Pure Mathematics
1985 University of Warwick, MSc, Mathematics Education
1988 University of Warwick, PhD, Mathematics Education
1987 Fellow of The Institute of Mathematics and Its Applications (FIMA), UK

Employment
Auckland University Mathematics Department: Professor 2010–2016; Associate Professor 2004–2009; Senior Lecturer 1997–2003; Lecturer 1993–1996

Honorary Appointments
Visiting Professorships: Nanyang Technological University, Singapore, 2012; Warwick University, UK, 2005

Academic Journal and Book Appointments
International Journal of Research in Undergraduate Mathematics Education, Editor-in-Chief, 2014–
Mathematics Education Research Journal Associate Editor 2001–3
Editorial boards: *Mathematics Education Research Journal* (MERJ) 2006 on; *Digital Experiences in Mathematics Education* 2014 on; *International Journal of Mathematical Education in Science and Technology* (IJMEST) 2009–14
Routledge book series on Integrating Mathematics Content and Pedagogy International Advisory Board
New Zealand Mathematics Magazine Editor 2001-2009
Reviewer for 5 A grade journals including ESM and JRME, plus many others

International Activities
International Congress of Mathematics Education (ICME): Invited lectures 2004 and 2016; survey team leader for Key Mathematical Concepts in the Transition from Secondary to University, 2009-2012.
Scientific Committee of International Conference on Technology in Mathematics Teaching (ICTMT) 2013-2017
2010-11 Co-chair Scientific Committee and Joint Proceedings Editor Delta 2011
2002 Convenor and proceedings editor Mathematics Education Research Group of Australasia (MERGA)
2000 Co–convenor and Proceedings Editor TIME2000 international technology conference
Invited talks at Cambridge, Warwick, Leeds, Swansea, Plymouth, Leicester, Southampton, East Anglia, OU (UK), Grenoble, Turin, Wuerzburg, Darmstadt, Tel Aviv, Taichung National (Taiwan), Nanyang Technological (Singapore) and Melbourne universities.

Selected Recent External Research Grants (from a total of >$1.57 million)
TLRI grants: PI 2006 $158355; PI 2008 $179033; AI 2009 $130000; PI 2009 $200000; AI 2013 $276900

Selected Recent Relevant Research Papers (from a total of 204 refereed papers)

Schoenfeld, A., Thomas, M. O. J., & Barton, B. (2016). On understanding and improving the teaching of university mathematics. *International Journal of STEM Education*, *3*(4). DOI 10.1186/s40594-016-0038-z
Hannah, J., Stewart, S., & Thomas, M. O. J. (2016). Developing conceptual understanding and definitional clarity in linear algebra through the three worlds of mathematical thinking. *Teaching Mathematics and Its Applications: International Journal of the IMA*. doi:10.1093/teamat/hrw001
Thomas, M. O. J. (2015). Inhibiting intuitive thinking in mathematics education. *ZDM Mathematics Education*, *47*(5), 865-876. DOI :10.1007/s11858-015-0721-4
Arzarello, F., Robutti, O. & Thomas, M. O. J. (2015). Growth point and gestures: Looking inside mathematical meanings. *Educational Studies in Mathematics, 90,* 19-37. DOI: 10.1007/s10649-015-9611-5
Hong, Y. Y., & Thomas, M. O. J. (2014). Graphical construction of a local perspective on differentiation and integration. *Mathematics Education Research Journal*. *27,* 183-200. DOI: 10.1007/s13394-014-0135-6
Barton, B., Oates, G., Paterson, J., & Thomas, M. O. J. (2014). A marriage of continuance: Professional development for mathematics lecturers. *Mathematics Education Research Journal, 27*(2), 147-164. DOI: 10.1007/s13394-014-0134-7
Thomas, M. O. J. & Yoon, C. (2014). The impact of conflicting goals on mathematical teaching decisions. *Journal of Mathematics Teacher Education, 17,* 227-243. DOI: 10.1007/s10857-013-9241-8
Thomas, M. O. J. & Hong, Y. Y. (2013). Teacher integration of technology into mathematics learning. *International Journal for Technology in Mathematics Education*, *20*(2), 69-84.
Heid, M. K., Thomas, M. O. J., & Zbiek, R. M. (2013). How might computer algebra systems change the role of algebra in the school curriculum? In A. J. Bishop, M. A. Clements, C. Keitel, J. Kilpatrick, & F. K. S. Leung (Eds.) *Third international handbook of mathematics education* (pp. 597-642), Dordrecht: Springer.

University of Auckland
ACADEMIC CV

NAME: **Jason Stephens, BA, MEd, PhD**
CURRENT POSITION: **Associate Professor**
DEPARTMENT: **Learning, Development, and Professional Practice**
FACULTY: **Education and Social Work**

Educational Qualifications
1991 University of Vermont, BA, History and Political Science
1994 Vanderbilt University, MEd, Secondary Social Studies Education
2004 Stanford University, PhD, Psychological Studies in Education

Employment
University of Connecticut: Assistant Professor (2004-11), Associate Professor (2011-2012);
The University of Auckland: Senior Lecturer 2012–2016; Associate Professor 2017 to present

2001 Academic Journal and Book Appointments

Frontiers in Psychology	Associate Editor, 2016-present
International Journal for Educational Integrity	Editorial Board, 2015-present
Journal of Moral Education	Editorial Board, 2012-2017
Gifted Child Quarterly	Editorial Review Board, 2012-2014
SAGE Open	Guest Editor, 2011, 2016
Frontiers in Educational Psychology	Associate Editorial Board, 2010-2012
Journal of Advanced Academics	Editorial Review Board, 2007-201
The Routledge International Handbook of Social Psychology of the Classroom	Co-Editor, 2015

Reviewer for top tier journals including the *AERJ, Journal of Educational Psychology,* and *Child Development*

Selected Invited Addresses, Lectures, and Workshops (from a total of 35)
How learning analytics can help promote student engagement and academic integrity (2016). Invited speaker for a 45-minute Webcast hosted by Turnitin.com: http://go.turnitin.com/Apac-Webcast-LearningAnalytics
Education without Borders: Open and Online Education (November 18, 2015). Invited panelist at the 7th Asia Pacific Conference on Educational Integrity: Albury, Australia.
Natural and Normative, but Neither Ethical nor Inevitable: The Problem of Cheating and Possibilities for Promoting Integrity (November 18, 2015). Invited keynote address at the 7th Asia Pacific Conference on Educational Integrity: Albury, Australia.
Fostering Academic Engagement and Student Interaction in Large Class Settings (February 20, 2013). An invited workshop for Teaching and Learning Day at the Faculty of Education. The University of Auckland. Auckland, New Zealand.

Selected External Research Grants (from a total of >$500,000 USD)
John Templeton Foundation: PI 2007-2011 USD$392,000; PI 2012-2013 USD$114,000

Selected Relevant Research Papers (from a total of 35 refereed papers)
Artino, A. R., Jr. & Stephens, J. M. (2009). Beyond grades in online learning: Adaptive profiles of self-regulated learners. *Journal of Advanced Academics, 20*(4), 568-601.
Artino, A. R., Jr. & Stephens, J. M. (2009). Academic motivation and self-regulation: A comparative analysis of undergraduate and graduate students in online courses. *The Internet and Higher Education, 12,* 146-151.
Stephens, J. M. (2016). Creating cultures of integrity: A multi-level intervention model for promoting academic honesty. In T. Bretag (Ed.), *Handbook of academic integrity* (pp. 995-1007). New Delhi: Springer Reference. DOI 10.1007/978-981-287-079-7_13-1.
Stephens, J. M. (2016). The SEALLS Project: A case of blending in technology to enhance Student Engagement and Achievement in Large Lecture Settings. In C. Gunn & L. Ramsay (Eds.), *Insights into practice: Teaching cases for student engagement and achievement.* (pp. 14-16). The University of Auckland: Centre for Learning and Research in Higher Education (CLeaR).
Stephens, J. M., Feinberg, J. R. & Zack, j. (2013). Those who do: Social studies teachers' use of role play and simulations and the making of 21st century citizens. In J. Passe & P.G. Fitchett (Eds.), *The status of social studies: Views from the field* (pp. 259-279). Charlotte, NC: Information Age Publishers.
Stephens, J. M., & Wangaard, D. B. (2016). The Achieving with Integrity Seminar: An integrative approach to promoting moral development in secondary school classrooms. *International Journal of Educational Integrity, 12*(3), 1-16. DOI: 10.1007/s40979-016-0010-1
Stephens, J. M. & Wangaard, D. B. (2013). Using the epidemic of academic dishonesty as an opportunity for character education: A three-year mixed methods study (with mixed results). *Peabody Journal of Education, 88*(2), 159-179. DOI: 10.1080/0161956X.2013.775868
Stephens, J. M., Young, M. F., & Calabrese, T. H. (2007). Does moral judgment go offline when students are online? A comparative analysis of undergraduates' beliefs and behaviors related to conventional and digital cheating. *Ethics & Behavior, 17*(3), 233-254.

References

Blondal, K. S., & Adalbjarnardottir, S. (2012). Student disengagement in relation to expected and unexpected educational pathways. *Scandinavian Journal of Educational Research*, *56*(1), 85-100.

Blumenfeld, P., Soloway, E., Marx, R., Krajcik, J., Guzdial, M. & Palincsar, A. (1991). Motivating project-based learning: Sustaining the doing, supporting the learning. *Educational Psychologist*, *26*(3&4), 369-398.

Bransford, J., Sherwood, R., Vye N., & Rieser, J. (1986). Teaching thinking and problem solving: Research foundations. *American Psychologist*, *41*, 1078-1089.

Braun, V. & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77-101.

Cramond, B., Matthews-Morgan, J., Bandalos, D., & Zuo, L. (2005). A report on the 40-year follow-up of the Torrance Tests of Creative Thinking: Alive and well in the new millennium. *Gifted Child Quarterly, 49*(4), 283-291.

Evans, J. S. B. T. (2003). In two minds: Dual process accounts of reasoning. *TRENDS in Cognitive Sciences, 7*(10), 454–459.

Falkner, N., Sooriamurthi, R. & Michalewicz, Z. (2010). Puzzle-based learning for engineering and computer science. *IEEE Computer, 43*(4), 20–28.

Falkner, N., Sooriamurthi, R., & Michalewicz, Z. (2012a). Teaching puzzle-based learning: Development of basic concepts. *Teaching Mathematics and Computer Science*, *10*(1), 183-204.

Falkner, N., Sooriamurthi, R., & Michalewicz, Z. (2012b). Teaching puzzle-based learning: Development of transferable skills. *Teaching Mathematics and Computer Science*, *10*(2), 245-268.

Fisher, A. (2001). *Critical Thinking: An Introduction*, Cambridge, UK: Cambridge University Press.

Fredricks, J. A., Blumenfeld, P. C., & Paris, A. (2004). School engagement: Potential of the concept: state of the evidence. *Review of Educational Research*, *74*, 59–119.

Furnham, A., Crump, J., Batey, M., & Chamorro-Premuzic, T. (2009). Personality and ability predictors of the “Consequences” Test of divergent thinking in a large non-student sample. *Personality and Individual Differences, 46*(4), 536-540.

Gilmore, C., Keeble, S., Richardson, S., & Cragg, L. (2015). The role of cognitive inhibition in different components of arithmetic. *ZDM Mathematics Education*, *47*(5), 771–782.

Gnadig, P., Honyek, G., & Riley, K. (2001). *200 puzzling physics problems, with hints and solutions*. Cambridge, UK: Cambridge University Press.

Guilford, J. P. (1959). Traits of creativity. In H. H. Anderson (Ed.), *Creativity and its cultivation* (pp. 142-161). New York: Harper & Brothers Publishers.

Haylock, D. (1987). A framework for assessing mathematical creativity in school children, *Educational Studies in Mathematics*, *18*(1), 59–74.

Haylock, D. (1997). Recognizing mathematical creativity in school children. *International Reviews on Mathematical Education*, *29*(3), 68-74.

Klymchuk, S., Zverkova, T., Gruenwald, N., & Sauerbier, G. (2010). University students' difficulties in solving application problems in calculus: Student perspectives. *Mathematics Education Research Journal (MERJ)*, *22*(2), 81-91.

Lee, C. S., Huggins, A. C., & Therriault, D. J. (2014). A measure of creativity or intelligence? Examining internal and external structure validity evidence of the remote associates test. *Psychology of Aesthetics, Creativity, and the Arts, 8*(4), 446–460.

Leikin, R. & Pitta-Pantazi, D. (2013). Creativity and mathematics education: The state of the art. *ZDM - The International Journal on Mathematics Education, 45*(2), 159–166.

Leikin, R. (2009). Exploring mathematical creativity using multiple solution tasks. In R. Leikin, A. Berman, & B. Koichu (Eds.), *Creativity in mathematics and the education of gifted students* (pp. 129–145). Sense Publishers: Rotterdam.

Meyer, E.F., Falkner, N., Sooriamurthi, R., & Michalewicz, Z. (2014). *Guide to teaching puzzle-based learning.* Springer: London

Michalewicz, Z., & Michalewicz, M. (2008). *Puzzle-based learning: An introduction to critical thinking, mathematics, and problem solving*. Hybrid Publishers: Melbourne.

Parhami, B. (2008). A puzzle-based seminar for computer engineering freshmen. *Computer Science Education*, *18*(4), 261-277.

Poundstone, W. (2000). *How would you move Mount Fuji? Microsoft's cult of the puzzle—How the world's smartest companies select the most creative thinkers*. Little Brown and Company.

Schoenfeld, A. H. (1985). *Mathematical problem solving*. Academic Press: New York.

Schoenfeld, A. H. (2010). *How we think. A theory of goal-oriented decision making and its educational applications.* Routledge: New York.

Selden, A, Selden, J, Hauk, S., & Mason, A. (2000). Why can't calculus students access their knowledge to solve non-routine problems? In A. Schoenfeld, J. Kaput, & E. Dubinsky (Eds.), *Research in Collegiate Mathematics Education* (Vol. 4, pp. 128–153). AMS (American Mathematical Society): Washington, DC.

Sriraman, B., & Haavold, P. (2016). Creativity and giftedness in mathematics education: A pragmatic view. In J. Cai (Ed.), *First compendium for research in mathematics education.* Reston: National Council of Teachers of Mathematics.

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

Thomas, M. O. J. (2015). Inhibiting intuitive thinking in mathematics education. *ZDM Mathematics Education*, *47*(5), 865–876.

Torrance, E. (1963). *Education and the creative potential*. University of Minnesota Press: Minneapolis.

Torrance, E. (1972). Predictive validity of the Torrance tests of creative thinking. *The Journal of Creative Behavior, 6*(4), 236-262.

Treffinger, D. J., Young, G. C., Selby, E. C., & Shepardson, C. (2002). *Assessing creativity: A guide for educators* (RM02170). Storrs: University of Connecticut, The National Research Center on the Gifted and Talented.

(2007). *Vision Mātauranga*. New Zealand Ministry of Research, Science and Technology.

8. Appendix: The Intentions Poster is on the next two pages

PO Box 3237
Wellington, New Zealand
e-mail: tlri@nzcer.org.nz

Project Title: Investigating the Impact of Non-Routine Problem Solving on Creativity, Engagement and Intuition of STEM Tertiary Students

TLRI grant holders:

Leading organisation: AUT

Principal Investigators: Associate Professor Sergiy Klymchuk, AUT; Emeritus Professor Mike Thomas, University of Auckland

Associate Investigators: Associate Professor Jason Stephens, Dr Julia Novak, Dr Tanya Evans, University of Auckland

Practitioners: Professor Sergei Gulyaev, Dr Jordan Alexander, Dr William Liu, AUT; Dr Andrew Zaliwski, Whitireia New Zealand; Priscilla Murphy, Manukau Institute of Technology.

Project start date: January 2018

Project Finish date: December 2019

Intro / Project description

Attrition among first-year STEM students occurs, not because courses are too difficult, but because they're "boring". This project aims to enhance student engagement in STEM courses through integration of solving non-routine problems during instruction. In addition, it investigates the effects of this pedagogy on student engagement and its influence on their intuition and creativity.

Aims

The primary aim of the proposed project is the implementation and evaluation of an innovative pedagogical intervention Puzzle-Based Learning (PzBL) in STEM courses. To fulfil this broad aim, this project will ask and answer three important questions, each with its own aim:

Does it work? Specifically, does the integration of non-routine problem-solving in lectures affect participants' engagement in lectures, as well as their ability to inhibit intuitive thinking and exhibit creative thinking? This question aims to test our hypothesis that participants will demonstrate increased engagement, greater ability to inhibit intuitive thinking and exhibit creative thinking.

Does it work for all participants? In other words, are the observed effects moderated by individual differences such as demographic characteristics or prior ability? Intervention effects are not always equally distributed, and the aim of this question is to test for that possibility. If detected, adjustments to the approach will be undertaken as warranted.

What do students think? This project aims to understand how learners feel about solving non-routine problems and the integration of PzBL in their lectures; the extent to which they found PzBL enjoyable and effective; what they liked most and least; and what they think could be changed to improve it.

Why is this research important?

The New Zealand government has identified the undersupply of students studying STEM subjects as a priority challenge to delivering its Business Growth Agenda (www.mbie.govt.nz). In answering the three questions above, and fulfilling their aims, we hope to offer an effective and scalable approach to enhancing student engagement and achievement in STEM courses. We also anticipate that this research will have positive effects on students' capacity to be creative and successfully confront non-routine problems. These are important workplace employee characteristics and would thus improve the employability of STEM students.

What we plan to do

To realise the aims described above, the proposed study will employ a mixed-method research design; specifically, a sequential design with both quantitative and qualitative research methods. This type of research design unfolds in a series of phases, each with its own set of purposes, data sources, and analyses and so advanced preparation is essential for successful execution of the design. Accordingly, we will spend the first six months of the project finalising procedures and measures (and ethics approvals) needed for the study. With these in place, implementation of the intervention will proceed in the following six months with three waves of data collection during the semester: 1) Week 1-2 students complete baseline questionnaire; 2) Weeks 2-10 classroom observations and individual interviews; 3) Week 12 students complete post-course questionnaire. Subsequently six months will be spent coding and analysing the data collected, and six months writing up and disseminating the results and their implications.

Our partners:

The partners in this project represent a rich array of disciplines and institutions as well as expertise and experience. Specifically, our core project team of ten comprises mathematicians, physicists, computer scientists, and educational psychologists (scholars and practitioners) from four tertiary institutions in New Zealand. Our partnership also includes a group of prominent "critical friends" to act as strategic advisors. These comprise Sir Vaughan Jones, a Distinguished Professor of mathematics at Vanderbilt University and recipient of a Fields Medal; Professor Merrilyn Goos, University of Queensland, Vice-President of the International Commission for Mathematical Instruction and Professor Glenda Anthony, Massey University, Co-Director of the Centre for Research in Mathematics Education and member of the PBRF Education panel.

Contact details

Principal Investigator: Sergiy Klymchuk, AUT, Associate Professor of Mathematics and Director of STEM Tertiary Education Centre (STEM-TEC)

Address: SECMS, AUT, Private Bag 92006, Auckland 1142
Phone: 09-921 9999 ext.8431
Email: sergiy.klymchuk@aut.ac.nz

Six team members (from the left): Dr William Liu, Professor Mike Thomas, Dr Tanya Evans, Associate Professor Sergiy Klymchuk, Priscilla Murphy, Associate Professor Jason Stephens.