Educating the Edisons of the 21st Century: Embedding tools of the Theory of Inventive Problem Solving (TRIZ) into the engineering curriculum

Final Report 2019

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https://edisons21.com
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## List of acronyms used

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>AAEE</td>
<td>Australasian Association for Engineering Education</td>
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<td>ACED</td>
<td>Australian Council of Engineering Deans</td>
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<td>ADTL</td>
<td>Australian Engineering Deputy Deans of Teaching and Learning</td>
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<td>ANU</td>
<td>Australian National University</td>
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<tr>
<td>ATLC</td>
<td>Australian Learning and Teaching Council</td>
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<td>AUT</td>
<td>Auckland University of Technology</td>
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<td>CSU</td>
<td>Charles Sturt University</td>
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<td>DET</td>
<td>Department of Education and Training</td>
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<td>EA</td>
<td>Engineers Australia</td>
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<td>ETRIA</td>
<td>European TRIZ Association</td>
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<td>EWB</td>
<td>Engineers Without Borders</td>
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<tr>
<td>IEEE</td>
<td>Institute of Electrical and Electronic Engineers</td>
</tr>
<tr>
<td>IUR</td>
<td>Ideal Ultimate Result</td>
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<tr>
<td>MATCEMIB</td>
<td>Mechanical, Acoustic, Thermal, Chemical, Electrical, Magnetic, Intermolecular, Biological</td>
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<td>MATRIZ</td>
<td>International TRIZ Association</td>
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<tr>
<td>RMIT</td>
<td>Royal Melbourne Institute of Technology</td>
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<tr>
<td>STC</td>
<td>Size-Time-Cost (Operator)</td>
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<tr>
<td>STEM</td>
<td>Science, Technology, Engineering and Mathematics</td>
</tr>
<tr>
<td>TERISSA</td>
<td>Task Evaluation and Reflection Instrument for Student Self-Assessment</td>
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<td>TOIT</td>
<td>Toi-Ohomai Institute of Technology</td>
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<tr>
<td>TRIZ</td>
<td>Theory of Inventive Problem Solving</td>
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<td>UNSW</td>
<td>University of New South Wales</td>
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<td>UoA</td>
<td>University of Auckland</td>
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<td>UQ</td>
<td>The University of Queensland</td>
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<td>USYD</td>
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Executive Summary

Fellowship: need, focus and activities

Over the last ten years, governments, technological associations, managers of engineering companies and world business leaders have identified cognitive skills and, specifically creativity skills, as vital for professionals of the 21st Century.

The need to change engineering curricula in order to educate engineers in creativity skills that meet the requirements of the engineering industry was raised over 50 years ago. In the 1960s, technical knowledge began to expand rapidly. This expansion was followed by redevelopment of engineering curricula to accommodate more teaching of narrow discipline courses and to focus more thoroughly on development of analytical skills and specific methods for solving instrumental problems. As a result, development of students’ creativity skills lagged significantly behind that of analytical skills. Since then, engineering curricula have not changed enough to ensure that creativity skills in graduates are appropriately developed. Recent research publications by scholars from Australia, the USA, Canada and France suggest that the development of divergent thinking skills in engineering students still significantly lags that of convergent thinking skills.

This Fellowship, titled ‘Educating the Edisons of the 21st Century: embedding tools of the Theory of Inventive Problem solving (TRIZ) into the engineering curriculum’, aimed to initiate and lead change in engineering curricula focused upon producing creative engineers capable of developing novel products and services in a fiercely competitive global market. In order to achieve this, the Fellowship team:

- Integrated existing educational resources developed by leading world academics who have introduced the Theory of Inventive Problem Solving (TRIZ) at their universities.
- Constructed a web-based repository of TRIZ educational materials (TRIZ or Fellowship Repository) on thinking heuristics that could be embedded into existing engineering courses and used by individual students for self-learning.
- Promoted the web-based repository of TRIZ teaching materials to Australian and international engineering academics and engineering students.
- Engaged students enrolled in engineering degrees in Australia and New Zealand in utilising TRIZ tools in their projects.
- Engaged engineering academics from Australia and New Zealand in introducing students to the basic tools of TRIZ with help of the TRIZ Repository.
- Connected Australian engineering academics with the international scholars who teach and research TRIZ.
- Disseminated the outcomes of the Fellowship at conferences and in peer-reviewed publications.

1 TRIZ is an English transliteration of the Russian acronym ТРИЗ for "Теория Решения Изобретательских Задач" (Theory of Inventive Problem Solving). TRIZ is a generic name for a family of heuristics (tools) for problem analysis, problem reframing, failure analysis and creative problem solving that was conceived in Russia in the 1950s (https://edisons21.com). See Chapter 3 below.
TRIZ Repository

The set of TRIZ heuristics for the Fellowship Repository was chosen to meet the following three criteria.

- Heuristics need to effectively enhance the ability of engineers to generate novel solutions.
- Heuristics must suit the development level of university students.
- Heuristics must be easy to embed into existing courses.

After analysis of ideation heuristics that most suit the engineering profession, 12 TRIZ heuristics were chosen for development of educational materials. Educational materials for seven heuristics became available from the Fellowship Repository in 2017 and the remaining five will be uploaded to the Fellowship Repository by the end of 2019.

The TRIZ Repository created by the Fellowship team is located at the https://edisons21.com website. As of February 2018, it contained educational materials for seven TRIZ heuristics, numerous research papers that discuss the application of TRIZ heuristics, and case studies that illustrate the application of the heuristics in real industrial settings. The educational materials can be used by individual students for self-learning. Additional materials that allow academics unfamiliar with TRIZ to introduce TRIZ heuristics in class are also provided.

Since the launch of the TRIZ Repository website in December 2016, it has been visited by over 2600 users from 70 countries, with over 17,000 page views during just over 4000 sessions. Nearly 55 per cent of the users were represented as Australian.

Promotion and dissemination

Over the 15 months of the Fellowship activities, more than 400 academics and more than 1300 students from Australia and New Zealand participated in face-to-face seminars, presentations, workshops and lectures delivered by the Fellow. Engineers Without Borders (EWB) Australia, the Golden Key International Honour Society (Golden Key) and other associations that closely cooperated with the Fellowship team promoted TRIZ Repository via emails and web links to over 6000 Australian students. These organisations also helped the Fellowship team promote the Edisons21.com Creativity Challenge, which was open to Australian students and required them to learn a TRIZ heuristic and apply it in their university project. Fifty-four students registered for the Challenge and the three winners participated in the Fellowship Convention and presented at the Fellowship workshop.

Fellowship activities culminated in the Fellowship Convention at the conference of the Australasian Association for Engineering Education (AAEE) (Sydney, December 2017). The Convention consisted of a special conference focus session, which attracted 17 research presentations by academics and practitioners from nine countries, and a Fellowship workshop, which was devoted to discussions of integrating creativity into curriculum and which engaged all three student winners of the Edisons21.com Creativity Challenge.
Outcomes and future plans

Fellowship activities achieved the original goal of raising awareness among Australian engineering Deans and Deputy/Associate Deans of the need to revisit engineering curricula and to devote more attention to development of student creativity skills over the four years of an engineering degree. The Fellow will be updating the Australian Council of Engineering Deans (ACED) in 2019 on the first outcomes of the Fellowship and will work with the Deputy Deans to involve more academics in teaching creativity heuristics.

The TRIZ Repository, and the first educational successes of using it, have been shared with hundreds of engineering academics from Australia and New Zealand. Academics from six universities used the materials provided by the Repository in 2017. Educators representing RMIT, Swinburne University of Technology, The University of Melbourne, Western Sydney University (WSU), Auckland University of Technology (AUT) and Toi-Ohomai Institute of Technology (TOIT) introduced students to TRIZ heuristics. Studies on application of TRIZ heuristics from the Fellowship Repository at Swinburne University of Technology and at TOIT have been published as peer-reviewed papers. Academics from at least six universities will be embedding teaching TRIZ heuristics into their discipline courses in 2018.

Surveys showed significant student approval of the quality of educational materials offered by the Repository and the suitability of these materials for self-learning. The surveys also revealed that application of heuristics helped students understand their university projects better and establish fresh ideas to successfully complete these projects. Surveyed academics found educational materials offered by the Fellowship Repository useful for their students and of good quality. Surveyed academics also indicated that these materials can be embedded into existing courses with minimal effort. Six peer-reviewed papers on the Fellowship activities were published in 2017. A book chapter and four more papers were published in 2018.

The Fellow will continue promoting the TRIZ Repository to academics and academic managers as well as holding discussions with ACED, ADTL and Engineers Australia on curricula changes that can produce creative graduate engineers. It is planned to cooperate with EWB Australia and Golden Key to engage more students in self-learning of creativity heuristics. The Edisons21 Creativity Challenge for 2019 is under preparation. Further studies on application of the TRIZ Repository have been conducted in 2018 at four universities and are proceeding in 2019 at three universities. The outcomes of these studies will be published, presented at conferences and promoted to ACED, ADTL, Australian engineering academics and at conferences locally and internationally. The Fellow will share the outcomes of activities with academics from non-engineering professions.

It is expected that educational materials for at least 12 TRIZ heuristics will be available from the Repository by 2019. Moreover, development of additional electronic resources (e.g. an app for every heuristic) is also planned.

The Fellowship has been instrumental in effecting change in engineering education and curricula in Australia. As Australia turns to STEM-educated professionals to lead innovation and change, the role of creative, innovative engineers will be vital. It is hoped that this Fellowship and the resulting innovations, tools and resources will leave a legacy well beyond
the funding period, and will further contribute to the future economic and social well-being of all Australians.
# Table of contents

Acknowledgements ................................................................................................................... iii

List of acronyms used ................................................................................................................ v

Executive Summary ................................................................................................................... vi

Fellowship: need, focus and activities .................................................................................. vi

TRIZ Repository .................................................................................................................... vii

Promotion and dissemination ............................................................................................. vii

Outcomes and future plans ................................................................................................ viii

Table of contents ................................................................................................................... x

Tables and Figures .................................................................................................................. xiii

Tables .................................................................................................................................. xiii

Figures ................................................................................................................................. xiii

Chapter 1: Engineering Education and the Fourth Industrial Revolution ......................... 1

Skills for the Fourth Industrial Revolution ............................................................................. 1

Is engineering education ready for the Fourth Industrial Revolution? ................................. 1

Definition of engineering creativity ....................................................................................... 3

Nurturing creative abilities in engineering graduates ........................................................... 3

Chapter 2: Thinking Heuristics for Engineering ................................................................... 5

How to ensure uptake of thinking heuristics? ....................................................................... 5

Which thinking heuristics to choose? .................................................................................... 5

Problem finding .................................................................................................................. 6

Idea generation ................................................................................................................... 7

Chapter 3: TRIZ Heuristics ..................................................................................................... 8

Why do TRIZ heuristics suit engineering students the most? ............................................... 8

Can TRIZ be taught effectively at university? ...................................................................... 9

TRIZ: what tools to teach at university? ............................................................................... 10
Appendix A ............................................................................................................................... 33
Certification by Deputy Vice-Chancellor .............................................................................. 33
Appendix B ................................................................................................................................ 34
Fellowship Evaluation Report .............................................................................................. 34
Appendix C ................................................................................................................................ 38
TRIZ Repository: Student comments ................................................................................... 38
Appendix D ................................................................................................................................ 41
TRIZ Repository: Comments from educators ........................................................................ 41
Appendix E ................................................................................................................................ 43
Reflection on learning and application of TRIZ heuristics ................................................... 43
Appendix F ................................................................................................................................ 44
Publications directly related to Fellowship activities .......................................................... 44
Appendix G ................................................................................................................................ 45
References ........................................................................................................................... 45
Appendix H ................................................................................................................................ 50
Fellowship Impact Plan ........................................................................................................ 50
Tables and Figures

Tables

Table 1. Classification of TRIZ heuristics that suit university students 10
Table 2. Events facilitated by the Fellow 18
Table 3. Students’ opinions on the usefulness of educational materials offered by the TRIZ Repository 29
Table 4. Students’ opinions on the influence of TRIZ heuristics 29
Table 5. Educators’ opinions on the usefulness of educational materials offered by the Repository 30
Table 6. Educators’ opinions on the usefulness of TRIZ heuristics 30
Table 7. Fellowship Impact Plan 50

Figures

Figure 1. The main web page of the Fellowship TRIZ Repository 14
Figure 2. Example of a Mind Maps with suggestions on how to use the TRIZ Repository 16
Figure 3. TRIZ Repository sessions and users: 1 December 2016 to 31 December 2017 17
Figure 4. The distribution of the sessions per country and device 17
Figure 5. Example of a link to the Fellowship Repository at the EWB site 21
Figure 6. Example of a Fellowship Convention promotion flyer 23
Figure 7. Presentation of a winner of the Edisons21 Creativity Challenge 24
Figure 8. A promotion card that contains steps of the Size-Time-Cost Operator heuristic 25
Chapter 1: Engineering Education and the Fourth Industrial Revolution

Skills for the Fourth Industrial Revolution

In the opinion of the World Economic Forum, the world has entered the Fourth Industrial Revolution (World Economic Forum, 2016):

*Developments in genetics, artificial intelligence, robotics, nanotechnology, 3D printing and biotechnology, to name just a few, are all building on and amplifying one another. This will lay the foundation for a revolution more comprehensive and all-encompassing than anything we have ever seen.* (p. v).

In order to succeed in the Fourth Industrial Revolution, companies require employees with a new and different skillset. Senior human resources officers and strategy executives from 371 individual companies, asked to identify skills essential for employment in 2020, suggested that the cognitive abilities will be in the highest demand (World Economic Forum, 2016, p. 22). Five of the top ten skills required for success in 2020 named by the World Economic Forum are cognitive in nature: (1) complex problem solving, (2) critical thinking, (3) creativity, (7) judgement and decision-making and (10) cognitive flexibility (Gray, 2016).

Recent reports from Deloitte and the Australian Government specifically mention problem solving and creativity skills as important for the success of Australian businesses by 2030 (Deloitte, 2017; Department of Employment, 2016). Over 800 CEOs of international corporations interviewed by IBM supported the importance of creativity in achieving company goals. They suggested that, to survive and prosper in a world of disruption, companies need to accelerate innovation (IBM Institute for Business Value, 2016).

Is engineering education ready for the Fourth Industrial Revolution?

Although the need for sound creativity skills mentioned above applies to all professions in the 21st Century, it is particularly important for the engineering profession. After all, the term *engineering* is derived from the Latin *ingenium*, meaning ‘cleverness’ and *ingeniare*, meaning ‘to contrive, devise’ (Wikipedia, 2017). It is not surprising that institutes of engineers all over the world have identified problem solving and creativity as vital skills for engineering graduates the 21st Century (ENAAE, 2015; Engineering Council, 2013; Engineers Australia, 2011; National Academy of Engineering, 2004).

Research findings on the achievements of engineering programs in nurturing creative graduates are inconclusive. A number of authors have reported on failures by current engineering programs to enhance students’ creativity (Daly, Mosyjowski & Seifert, 2014; Sola, Hoekstra, Fiore & McCauley, 2017; Steiner, Belski, Harlim, Baglin, Ferguson, & Molyneaux, 2011). In contrast, there are reports on successes in enhancing problem solving and creativity among engineering students (Belski, Baglin & Harlim, 2013; Hugh, Alan, Ira, Satyandra, Lawrence, Edward, & Brent, 2007).
Recent findings by Valentine, Belski and Hamilton (2017) reveal a lack of focus on creative problem solving in Australian engineering curricula. Valentine et al. reviewed all Australia-based engineering single degrees accredited by Engineers Australia that (i) were offered during the first half of 2017, (ii) had the word ‘electrical’ in the title of the degree, and (iii) provided program handbooks on the web. Overall, the authors considered 34 study programs offered at 25 Australian universities. Although these 34 programs comprised 919 core courses, only 20 course outlines at 17 institutions explicitly stated that concepts related to creativity and/or innovation are demonstrated or explained to students. Valentine et al. (2017) were unable to identify any program that included core courses explicitly exposing students to, or requiring application of, creativity heuristics or techniques. Additionally, it was found that only a limited number of course learning outcomes mentioned the need for students to demonstrate creativity and innovation.

Educating creative engineers is a permanent challenge for engineering education in many countries. Daly et al. (2014), who examined the learning outcomes of engineering courses at a number of universities in the United States of America (USA), found that these courses adequately addressed development of convergent thinking skills but contained little instruction on creativity skills. Gaudron and Kövesi (2017) recently analysed the opinions of French engineering students on the skills they would need to innovate, as well as their perceptions on gaining these skills while studying engineering. The biggest divergence in views between the importance of the skill and the successful acquisition of that skill at university was in views of creativity (4.2 versus 1.7 on a 5-point Likert scale, 1 = complete disagreement, 5 = complete agreement) (Gaudron & Kövesi, 2017).

Due to the substantial volume and complexity of engineering technology professionals must possess, the majority of engineering programs over many decades have devoted minimal attention to development of divergent thinking skills. Engineering curricula have been overloaded with courses that teach specialised discipline knowledge. Over 50 years ago, just as the volume and complexity of engineering discipline knowledge started its rapid expansion, Olken (1964) reflected on the importance of creativity training for engineers and the inability of engineering education to nurture creative graduates.

> If our inventors of the future are to have the higher analytical abilities needed to cope with our increasingly technical inventions, the present overemphasis or unbalance of analytical training relative to training in creativity will increase even more rapidly than our present creativity training courses will be able to correct it. We will therefore need much greater development and expansion of creativity training in engineering schools than are now planned, merely to keep the imbalance at its present level. In short, as far as the future is concerned in creativity training of engineers, we will have to run much faster just to stand still. (Olken, 1964, p. 156).

The findings of Valentine et al. (2017), Gaudron and Kövesi (2017) and Daly et al. (2014) show that Olken’s reflection is as relevant today as it was 50 years ago. Clearly, the challenges of educating creative engineers have not been resolved and are still on the agenda of engineering educators.
Definition of engineering creativity

In order to establish effective ways of enhancing creativity in engineering graduates, it is necessary to define the meaning of creativity in engineering. In the 20th century, creativity scholars defined creativity as a general skill. They viewed this general creativity skill as identical across all areas of human activity and, therefore, as transferable from one domain to another.

Later research findings suggest that a person who is creative in one domain is not necessarily creative in another domain (even if this second domain is adjacent to the first) (Baer, 2012; Weisberg, 2006). Scholars studying the outcomes of creativity training over the past ten years report negligible transfer of creativity training gains to other knowledge domains (Baer, 2016). These findings imply that creativity is domain-specific (Baer, 2015).

Recently, I have proposed a definition of engineering creativity based on analysis of legal aspects of patentability and patent authorship (Belski, 2017). First, analysis of authorship reveals that law courts consider the creator of an invention to be the person who originally developed the idea for the invention. This implies that creativity is a human ability to generate solution ideas. Second, to meet the legal criteria of patentability, the idea needs to solve an open-ended problem, be novel, not obvious to an expert and accepted by the individual as possible. Consequently, engineering creativity has been defined as

*the ability to generate novel solution ideas for open-ended problems, ideas that are not obvious to experts in a particular engineering discipline and that are considered by them as potentially useful.* (Belski, 2017, p. 327; emphasis added)

Interestingly, this definition of engineering creativity can be viewed as an expansion and clarification of the definition given by Harris nearly 60 years ago:

*the ability to produce a number of original ideas when confronted with problematic situation.* (Harris, 1960, p. 254; emphasis added)

With this definition in mind, let us investigate what engineering educators can do in order to produce engineering graduates with creativity skills adequate for the challenges of the Fourth Industrial Revolution.

Nurturing creative abilities in engineering graduates

I have been trying to engage engineering students in acquiring advanced thinking skills for many years. In 1996, after realising that my students could not properly analyse basic tasks on electric circuits, I developed the Task Evaluation and Reflection Instrument for Student Self-Assessment (TERISSA) – a heuristic that engaged students in evaluating task complexity and reflecting on the reasons for their evaluation prior to and after solving the problem (Belski & Belski, 2014). TERISSA has been used by numerous academics and helped many students improve their course performance in engineering and beyond (Belski & Belski, 2014; Harlim, DeSilva & Belski, 2009).
Subsequently, I started embedding other simple thinking heuristics into discipline courses I taught. Heuristics such as Six Thinking Hats and Random Entry and Provocations, developed by de Bono (1995), as well as tools of TRIZ such as Substance-Field Analysis, 40 Innovative Principles and Situation Analysis, were well accepted by the students. Student successes in applying these thinking heuristics to their projects made it clear that effective ideation methodologies need to be taught to students explicitly. In 2006, I introduced an RMIT-wide elective dedicated to learning four heuristics of the Theory of Inventive Problem Solving (TRIZ) (Belski, 2009; Belski et al., 2013). Although the TRIZ course was popular and resulted in statistically significant growth in students’ problem solving self-efficacy (Belski et al., 2013), it was not a core course and has been taken only by around five per cent of engineering students enrolled at RMIT in any particular semester. Most engineering disciplines permit students to enrol in maximum of two university-wide electives, and it is challenging to make a choice out of hundreds of courses on offer. Moreover, engineering program coordinators usually recommend students enrol in the discipline electives instead of taking an elective not related to engineering. They argue that a discipline elective will help engineering students further upgrade their discipline knowledge. It became evident that elective courses that teach thinking heuristics are unable to guarantee that all engineering graduates acquire advanced cognitive skills. In order to engage all engineering students in enhancement of thinking skills, therefore, core engineering courses must introduce learners to effective thinking heuristics.
Chapter 2: Thinking Heuristics for Engineering

How to ensure uptake of thinking heuristics?

Numerous thinking heuristics have been developed by practitioners from different disciplines to improve their work outcomes (e.g. Belski, 2007; de Bono, 1990; King & Schlicksupp, 1998; Osborn, 1953; Rivin & Fey, 1996). Based on the definition of creativity referred to in Chapter 2 and my experience of teaching thinking heuristics to students and practising engineers, as well as taking into account research findings, I established three criteria to select the heuristics that can be embedded into existing core courses and will best suit engineering students and engineering educators.

Criterion 1.
These heuristics need to effectively enhance the ability of engineers to generate novel solutions. Therefore, it was necessary to identify the heuristics considered by engineering experts to effectively enhance their ability to innovate.

Criterion 2.
These heuristics must suit the development level of university students. To ensure that students will be able to learn and use these heuristics, their prior knowledge and practical experience must be adequate for successful acquisition of the tools.

Criterion 3.
These heuristics must be easy to embed into existing courses. For these heuristics to be ‘accepted’ by course coordinators who may not be proficient with them, it would be beneficial if (i) these heuristics required only one or two weeks of a semester to learn and practice, (ii) all educational materials were provided to course coordinators free and did not require a significant investment of time to adapt to an individual discipline course, and (iii) the educational materials were suitable for self-learning.

Which thinking heuristics to choose?

To meet the requirements of Criterion 1, a heuristic needs to effectively aid engineering professionals in generating novel ideas. Research findings suggest that the ability to generate novel solutions is largely determined by two skills. The first is related to a person’s capacity to analyse a situation. This skill has many names, including situation analysis, situation appraisal, problem finding, problem setting, problem framing, problem construction etc. The second skill that determines a person’s ability to propose fresh ideas is associated with the skill of idea generation per se – the ability to propose diverse ideas.

The skills of problem finding and idea generation are closely related, even intertwined. When conducting situation analysis, a user often reframes the problem and, as a result, perceives it from an unexpected viewpoint. This unexpected perspective can generate novel solutions. As Charles F. Kettering, vice-president and director of research for General Motors (1920–47) once said, ‘A problem well stated is a problem half-solved’ (Boyd, 2002). Similarly, the ability to propose diverse solutions can help in problem reframing. After formulating an idea, a practitioner usually assesses whether the idea can resolve the problem. Assessment of idea suitability often helps in discovering new situation constraints or available resources that have not been recognised originally, as well as in questioning aspects of the problem that
previously seemed well-defined. This, in turn, results in reframing the problematic situation. The aspects of problem finding and generation of diverse ideas (idea generation) were considered separately in this report and are described below.

**Problem finding**

Approximately 14 years employment as an engineer in electronics and telecommunications, and over 20 years of consultation work on engineering design and problem solving, has taught me that real engineering problems are not as clear-cut as those resolved by students at university. A significant gap exists between the situations that face engineers in industry and problems that are offered to students at university. Engineers are not usually presented with problems per se; they face situations that need improvement. These situations frequently appear complex and combine numerous problems. In order to apply engineering principles learned at university, these complex situations need to be first untangled and reconstructed into instrumental problems – problems suiting application of discipline knowledge gained at university. Furthermore, the majority of real situations that engineers are asked to resolve contain a significant portion of non-technical issues. It is vital for an engineering practitioner to fully recognise these human-related issues prior to addressing the technical side of the situation.

Schön reflected on this gap between the demands of real-world practice and professional knowledge over 30 years ago:

> In real-world practice, problems do not present themselves to the practitioner as given. They must be constructed from the materials of problematic situations which are puzzling, troubling, and uncertain. (Schön, 1987, p. 40)

The importance of problem finding has been established by research into the approaches of famous design innovators and engineering experts. The strategy of situation analysis and framing played an extremely important role in development of successful artefacts (Belski, Teng, Belski & Kwok, 2016c). Famous design innovators have framed problems by conducting diverse activities: (a) altering the initial constraint set (Akin, 1990); (b) reassessing the problem from first principles (Cross, 2001, 2003; Cross & Cross, 1996); (c) re-evaluating the product’s application (Cross, 2001); (d) identifying the key question to be addressed (Candy & Edmonds, 1996); (e) immersing themselves in the problem situation, studying it in depth and reflecting (Maccoby, 1991; Roy, 1993); and (f) changing the focus of task analysis from the systems level to the level of individual elements and then back again (Maccoby, 1991).

Recent studies further support the importance of problem finding for developing novel ideas (Belski, Adunka & Mayer, 2016a; Harlim & Belski, 2013, 2017). Belski, Adunka and Mayer (2016a), for example, surveyed engineers and engineering researchers from companies that have been on the Thomson Reuters list of ‘100 Global Innovators’ for at least two of the three years from 2012 to 2014. When asked to identify the stage of problem solving that most influences the ability to propose novel ideas, all 46 study participants ranked the stage of identifying and understanding the problem above all other stages. Harlim and Belski (2013, 2017) established the primary importance of situation analysis by surveying and interviewing over 200 engineers and engineering students. This evidence supports the need to teach engineering students heuristics that can assist in problem finding.
Idea generation

Another area of focus for nurturing engineers’ ability to propose novel ideas is related to the enhancement of the skill of generating diverse ideas. Over many years of study and practice, engineers acquire significant domain knowledge and skills, which help professionals to solve instrumental problems but are not very useful for developing solutions outside their narrow technical field. Situations faced by engineers in their real-life practice often require them to suggest ideas that are outside their area of specialisation.

The ability of thinking heuristics to aid in idea generation has been evidenced by findings from industry and academia. Scholars of engineering creativity who studied the methods used by famous designers discovered that some great designers even developed their own heuristics to produce winning ideas. Examples include (a) engaging in mental transfer of technology from one application to another (Roy, 1993), (b) identifying analogies between the problem and various other products with similar functionality (Roy, 1993), and (c) formulating the ‘Ideal Ultimate Result’ and reflecting on the barriers to its achievement (Belski et al., 2016c).

The effectiveness of thinking heuristics that can act as catalysts during idea generation was supported by 46 study participants in the survey conducted by Belski et al. The level of agreement with the statement ‘creativity techniques that I have learned over the years have significantly improved my ability to solve engineering problems creatively’ (7.74/10) was the second highest after the importance of general knowledge (8.41/10) and exceeded in value discipline knowledge (7/10) and practical experience (7.21/10) (Belski et al., 2016a).

A recent study at Philips reported on the effectiveness of simple heuristics of Substance-Field Analysis and the Eight Fields of MATCEMIB for triggering novel ideas. Dobrusskin, Belski and Belski (2014) surveyed 13 members of a project team that was developing solution ideas for a technical problem in an area well protected by patents that did not belong to Philips. The team members learned and applied the heuristics during a one-day group idea-generation session. The team rated the influence of these two heuristics on their ability to develop new ideas very highly. The mean value of the team members’ response to the statement ‘In my view the use of the Su[bstance]-Field procedure generated ideas that would have been overlooked otherwise’ was 4.11/5 (a Likert scale of 5 was used: 5 – strongly agree, 1 – strongly disagree) (Dobrusskin et al., 2014, p. 126). The same mean value of 4.11/5 was achieved for the statement ‘the Eight Fields of MATCEMIB have helped me to thoroughly search my knowledge for solution ideas on the Project X’ (p. 126).

The ability of the heuristic of the Eight Fields of MATCEMIB to trigger novel ideas has been supported by numerous experiments involving over 1500 engineering students from six countries. It was found that this simple heuristic statistically significantly increases the number of diverse ideas proposed by subjects for an open-ended problem (Belski, Belski, Berdonosov, Busov, Bartlova, Malashevskaya, Kässie, Kutvonene, & Tervonene, 2015; Belski, Hourani, Valentine & Belski, 2014; Belski, Livotov & Mayer, 2016b). Daly, Yilmaz, Christian, Seifert and Gonzalez (2012) report that a number of design (thinking) heuristics helped engineering students to propose more ideas.

The successes of simple heuristics in enabling both experts and novices to propose more ideas suggest it would be advantageous to teach ideation heuristics at engineering schools.
Chapter 3: TRIZ Heuristics

Why do TRIZ heuristics suit engineering students the most?

TRIZ (Theory of Inventive Problem Solving) is a generic name for a family of heuristics (tools) for problem analysis and creative problem solving that was conceived in Russia in the 1950s (Altshuller, 1984). It is grounded on analysis of thousands of patents that reveals important trends in the development of artefacts. The original six TRIZ tools, known as the ‘classical TRIZ’, were developed specifically for engineering design practice. Since then, the TRIZ family has been expanded to over 20 tools (including software) that now cover practically all aspects of engineering practice, including research. Unlike Brainstorming and the Lateral Thinking tools of de Bono, which help a practitioner to generate countless ideas that are often of little relevance to the engineering issue under consideration, TRIZ guides engineers to creative ideas that are task-specific. This makes TRIZ particularly effective for problems faced by engineers. A survey of expert engineers – from companies considered by Thomson Reuters among the 100 most innovative in the world – established that practising engineers see TRIZ as the most valuable ideation toolset for the engineering profession (Belski et al., 2016a).

Since the 1990s, TRIZ has established a large number of followers worldwide. There are numerous reports on the successful use of TRIZ by engineering companies including industry leaders such as Intel, Apple, Boeing, Ford, Cochlear, General Electric (GE), IBM, LG, Procter and Gamble, Samsung, Philips, and Siemens. Coincidently, all these companies were listed by Thomson Reuters among the 100 most innovative engineering companies of 2011–2015 (Thomson Reuters, 2015). In 2008, Intel declared that ‘TRIZ is a key systematic innovation platform for Intel into the 21st Century’ (Roggel & Austin, 2008).

In the current competitive climate, corporations tend to withhold information on the sources of their successes. The following facts are available on the impact of TRIZ on research and development (R&D) and manufacturing at Samsung, which recently overtook Sony as the world leader in electronics. Samsung introduced TRIZ to its engineers and researchers in 1998 (Samsung SDI, 2014). Four years later, Samsung’s Advanced Institute of Technology (SAIT) awarded Dr Nikolay Shpackovsky, a Russian TRIZ expert who led a team of three TRIZ experts in training 2000 engineers and researchers in TRIZ, for having saved ‘approximately 120 billion [just over US$90 million] and improved SAIT’s R&D performance through application of TRIZ’ (TRIZJournal, 2002). In 2004, Samsung Electronics reported savings of US$70 million and revealed that ‘more than 100 patents are produced by applying TRIZ to R&D projects’ (Kim, Lee & Kang, 2005). Forbes magazine recently concluded that Samsung has ‘made it [TRIZ] the company’s religion’ (Shaughnessy, 2013a) and reported that to achieve this, Samsung trained over 1000 engineers in TRIZ in 2004 alone (Shaughnessy, 2013b). It is important to note that in January 2016, Bloomberg named Samsung as a driving force behind South Korea becoming the most innovative country in the world (Bloomberg, 2016). In recent years, a number of case studies that offer evidence on TRIZ’s effectiveness in engineering design and development have been published in peer-reviewed books, journals and conferences (Belski et al., 2016c; Cempel, 2013; Chen & Huang, 2015; Sheu & Hou, 2013; Dobrusskin et al., 2014; Swee, Yip, Keong, Tai & Toh, 2015).
I know of the power of TRIZ to uncork the spring of creative engineering ideas from my own experience. I was introduced to TRIZ in 1982, a few years after I started my engineering research career. Within the first 10 years of using TRIZ heuristics, I received 24 patents. Seven of them were used by Russian industry and, by 1993, had delivered a documented ‘economic effect’ equivalent to US$3,000,000.

**Can TRIZ be taught effectively at university?**

TRIZ basics (including software) are taught to engineering students at universities in many countries including Australia, China, the Czech Republic, Finland, France, Germany, India, Italy, Israel, Mexico, Taiwan, Singapore, South Korea, Russia, the UK and the USA. In 2011, the Russian Ministry of Education made teaching TRIZ basics compulsory in some engineering disciplines at all (over 60) State Universities.

Teaching TRIZ, as with teaching any tool that develops students’ cognitive skills, is guided by two main approaches: ‘enrichment’ and ‘infusion’ (Nickerson, 1994). In the enrichment approach, TRIZ modules are taught as a separate subject. For example, I introduced a subject fully devoted to TRIZ at RMIT in 2006 (Belski, 2009; Belski et al., 2013). Although the evidence supports the higher effectiveness of the enrichment approach in teaching cognitive skills, engineering curricula rarely utilise this approach. This is largely because engineering curriculum designers judge there is insufficient space in the already crowded, discipline-specific, knowledge-rich curriculum to accommodate special subjects focused solely on cognitive skills. Therefore, most universities that teach TRIZ deploy infusion strategies, embedding the teaching into discipline-based curricula (Barak, 2013; McGuinness, 2005).

Considerable evidence exists that TRIZ instruction makes a significant difference in the novelty of ideas proposed by students during design/project work (Becattini, Borgianni, Cascini, & Rotini, 2013; Berdonosov, 2013; Dumas & Schmidt, 2015; Livotov, 2013; Ogot & Okudan, 2006; Schrieverhoff & Lindemann, 2012). Our analysis revealed that the TRIZ subject at RMIT produced a statistically greater enhancement of students’ self-efficacy in creative problem solving than the four years of an RMIT engineering degree (Belski et al., 2013).

The suitability of simple TRIZ tools that can be learned in just a few hours for infusion into engineering units has been confirmed experimentally. In a recent study, students from one experimental group were exposed to eight random words (de Bono technique) that were shown to them for two minutes each. Students from the other two experimental groups were influenced by eight words that represented the Eight Fields of MATCEMIB (Mechanical, Acoustic, Thermal, Chemical, Electrical, Magnetic, Intermolecular, Biological; MATCEMIB belongs to the TRIZ heuristic of Substance-Field Analysis). The students from a fourth group were not influenced in any way – this group represented a control group. All students were given 16 minutes of tutorial time to individually generate as many ideas as possible for the same problem (suggested by Engineers Without Borders (EWB)). Students who were exposed to the words representing the MATCEMIB fields during idea generation proposed more and broader solutions than students from the control group (Belski et al., 2014). This study has recently been repeated at universities in the Czech Republic, Finland, Germany, Italy and the Russian Federation (Belski et al., 2016b; Buskes & Belski, 2017). The original results on the influence of MATCEMIB on idea generation have been fully replicated. Furthermore, the result of the latter study further supported the superiority of TRIZ tools over de Bono
techniques in idea generation for engineering. It was discovered that the influence of eight random words (de Bono technique) on the number and the breadth of ideas differed significantly between the countries and did not match the positive and stable influence of the words that represented the Eight Fields of MATCEMIB.

In another recent study, it was established that students can learn the basics of Substance-Field Analysis effectively while studying fully online and without any help from a teacher (Valentine, Belski & Hamilton, 2015). It was also discovered that devoting one hour of tutorial time to watching an introductory video on the heuristic of the Eight Fields of MATCEMIB and generating ideas with this heuristic resulted in significantly improved long-term idea generation performance (Valentine, Belski & Hamilton, 2016).

**TRIZ: what tools to teach at university?**

The choice of TRIZ heuristics in this Fellowship is based on evidence collected by researchers from engineering, design and cognitive science over the last 50 years. Table 1 presents the list of TRIZ heuristics that have been demonstrated as effective in engineering practice and fulfil the three criteria for the heuristics that can be embedded into the existing core courses at university (discussed in Chapter 2). All heuristics in Table 1 are divided into two groups: heuristics suiting undergraduate students and those suitable for postgraduate students. Indeed, postgraduates can also effectively learn the tools from both heuristic groups.

Table 1. Classification of TRIZ heuristics that suit university students (*indicates knowledge required by students commencing engineering and science degrees)

<table>
<thead>
<tr>
<th>Suitability</th>
<th>Tool</th>
<th>Criterion 1</th>
<th>Criterion 2</th>
<th>Criterion 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undergraduate students</td>
<td>Situation Analysis</td>
<td>Very Effective</td>
<td>Somewhat Effective</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Method of Smart Little People</td>
<td>Effective</td>
<td>Effective</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Operator Size-Time-Cost</td>
<td>Very Effective</td>
<td>Effective</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Notion of the Ideal Ultimate Result</td>
<td>Effective</td>
<td>Effective</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Fields of MATCEMIB</td>
<td>Not Effective</td>
<td>Very Effective</td>
<td>Medium*</td>
</tr>
<tr>
<td></td>
<td>Substance-Field Analysis</td>
<td>Very Effective</td>
<td>Very Effective</td>
<td>Medium*</td>
</tr>
<tr>
<td></td>
<td>Notion of Resources</td>
<td>Somewhat Effective</td>
<td>Very Effective</td>
<td>Medium*</td>
</tr>
<tr>
<td>Postgraduate students</td>
<td>Separation Principles</td>
<td>Somewhat Effective</td>
<td>Effective</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Method of the Ideal Result</td>
<td>Very Effective</td>
<td>Very Effective</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>Contradiction Table</td>
<td>Not Effective</td>
<td>Effective</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>40 Innovative Principles</td>
<td>Somewhat Effective</td>
<td>Effective</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>Nine Screens</td>
<td>Effective</td>
<td>Effective</td>
<td>Medium</td>
</tr>
</tbody>
</table>
Table 1 also depicts the effectiveness of TRIZ heuristics that have been chosen for development of appropriate study materials. These heuristics satisfy all the three criteria discussed in detail in Chapter 2. These heuristics are effective aids in problem framing and idea generation, which expert engineers see as important for creativity (Criterion 1). They satisfy the requirements on prior knowledge and practical experience of learners (Criterion 2). These heuristics are simple and easy to learn, and do not require much effort to be taught by an engineering educator who is not familiar with the heuristic (Criterion 3).
Chapter 4: Fellowship Activities

Fellowship activities were designed to:

(i) Develop a repository of TRIZ heuristics that can be used by students for self-learning and by academics to introduce a thinking heuristic in less than one hour and with minimal effort from the academic.
(ii) Engage engineering students in learning the thinking heuristics.
(iii) Engage engineering educators in embedding thinking heuristics into their existing discipline courses.
(iv) Engage engineering Deans, Deputy/Associate Deans (T&L) as well as engineering academics in review of engineering curricula in order for them to include explicitly teaching thinking heuristics to students in curricula.

Fellowship team

The Fellowship team consisted of five members of the Fellowship Expert team, five members of the Reference Group, two officers of the Support Group and the Independent Assessor.

Fellowship Expert team

Five engineering academics who have taught TRIZ at university-level for five to 20 years and use TRIZ in their research supported the Fellowship and provided their educational materials as well as contributing case studies and research papers to the Fellowship Repository under the Creative Commons licence. The Fellowship Expert Team consisted of the following academics.

Professor Pavel Livotov, Offenburg University of Applied Sciences, Germany, has taught TRIZ for over 10 years. He was President of the European TRIZ Association (ETRIA) until late 2017.

Professor Gaetano Cascini, Polytechnic University of Milan, Italy, has taught TRIZ in Italy for over 15 years. He is a past President of ETRIA.

Professor Leonid Chechurin, Lappeenranta University of Technology, Finland, has taught TRIZ for over five years. For a number of years he was the Vice-President (Education) of the International TRIZ Association (MATRIZ).

Professor Victor Berdonosov, Komsomolsk-on-Amur State University of Technology, Russia, has taught TRIZ to his students for over 20 years. He has initiated incorporation of TRIZ in the project work of students from China, Russia and South Korea and facilitated numerous online international student TRIZ conferences.

Associate Professor Bohuslav Busov, Brno University of Technology, Czech Republic, has taught TRIZ for over 15 years. He has trained over 2000 engineers in TRIZ from the Czech and Slovak Republics.
Reference Group

Five engineering experts whose work was closely associated with designing novel engineering artefacts and generating innovative business ideas supported the Fellowship as members of the Fellowship Reference Group. The Fellowship Reference Group consisted of the following members.

**Dr Oliver Mayer**, General Electric (GE) Global Research, Germany, has used numerous thinking heuristics over the years to develop numerous products and is one of the GE leaders in TRIZ application and training.

**Mr TENG Tat Chong**, Singapore Technologies Kinetics, Singapore, has led company innovation portfolio for over 15 years and engaged hundreds of company engineers in learning TRIZ heuristics.

**Mr Christoph Dobruesskin**, Philips, The Netherlands, has been helping Philips’ project teams for more than 10 years to learn TRIZ heuristics and to apply them for new product development and for process improvement.

**Mr Mark Berelowitz** has been an active TRIZ user at Cochlear for over 10 years.

**Mr Christian Klopfer**, currently at the National Australia Bank, has been using thinking heuristics (including TRIZ) since starting his engineering career at Bosch Australia over 15 years ago.

**Mr Enn Vinal**, one of the expert innovators at Telstra, who has played an important role in development of the Victorian chapter of the Institute of Electrical and Electronic Engineers (IEEE) – the biggest engineering association in the world.

Fellowship Support Group

My day-to-day Fellowship work was supported by Dr Jennifer Harlim and Mr Andrew Valentine. Dr Harlim dealt with administrative tasks and led the development of Fellowship promotional materials. Mr Valentine supervised the implementation of the website for the TRIZ Repository and also developed the Web-based Solution Templates for all heuristics. As a PhD student, Dr Harlim investigated the differences of problem-solving approaches of engineering experts and novices and continues to conduct research in the field of engineering education. In his current PhD research, Mr Valentine is exploring the suitability of web- and computer-based resources for enhancing students’ creativity.

Independent Fellowship Assessor

**Professor Roger Hadgraft**, a civil engineer with more than 20 years involvement in leading program renewal in engineering education, was the Independent Fellowship Assessor. Professor Hadgraft is an Australian Learning and Teaching Council (ALTC) Discipline Scholar in Engineering and ICT. Currently he is Director, Educational Innovation and Research at the University of Technology Sydney (UTS).
Fellowship repository of educational materials: TRIZ Repository

As discussed above, in order to help engineering educators with embedding thinking heuristics into existing discipline courses, it is necessary to equip them with educational materials on effective thinking heuristics that can be used during lectures and tutorials with minimal time investment by the educators themselves. The members of the Fellowship Expert team and the Fellowship Reference Group, as well as many other TRIZ practitioners, provided various educational resources for redevelopment and upload to the web-based Fellowship Repository of educational materials – the TRIZ Repository.

Originally, the TRIZ Repository was developed on the Drupal platform and was located at one of RMIT’s servers. Due to the decision to close this server and to discontinue support of Drupal sites made by RMIT in late 2016, the Repository was transferred to a private server in October 2017. Its web address stayed the same: https://edisons21.com.

The main web page of the TRIZ Repository is shown in Figure 1.

![Figure 1. The main web page of the Fellowship TRIZ Repository](image)

Contents of the TRIZ Repository

As shown in Figure 1, the TRIZ Repository offers its user four kinds of resources. The resources can be found in the navigation bar of the site and include educational materials for self-
learning, educational materials for academic use, research papers and case studies on application of TRIZ heuristics.

Tools of TRIZ
By opening the tab ‘TRIZ Tools’ a visitor will find educational resources that can be used by students for self-learning of simple TRIZ heuristics and by academics for introduction of these heuristics during lectures and tutorials. Educational resources for most of the heuristics consist of (i) a short video that explains how to use the heuristic, (ii) a ‘solution template’ that has been created as a PDF form, (iii) a web-based ‘solution template’ that is similar to the solution template and permits a user to follow the steps of the heuristic directly on the web, (iv) a heuristic ‘cheat sheet’ that presents the heuristic steps in a concise manner and (v) a PowerPoint presentation for introducing the heuristic that can be used by academics in class. The first four resources can be used by students to learn TRIZ heuristics on their own as well as in class. The PowerPoint presentation is supplied to aid academics in introducing TRIZ heuristics and to ensure that they will be able to prepare lectures and tutorials on TRIZ heuristics with minimal time investment or prior knowledge.

All educational videos have been stored at RMIT YouTube Channel. Only the links to these videos are offered by the TRIZ Repository. The video on Rule 1 of the Substance-Field Analysis Heuristic was uploaded to the Repository in late November 2016. The set of materials for the Eight Fields of MATCEMIB heuristic was uploaded in early December 2016, before the AAEE 2016 conference. Materials for the Size-Time-Cost (STC) Operator heuristic were ready by late January 2017. The Ideal Ultimate Result heuristic was available from late February 2017. By the beginning of the first semester of 2017 at Australian universities, the TRIZ Repository offered complete sets of educational materials on three TRIZ heuristics and some materials for the heuristic of the Substance-Field Analysis. Materials for the Resources heuristics became available in early May 2017. From October 2017 students were able to study the heuristic of Situation Analysis. It is expected that, by the end of 2019, the TRIZ Repository will offer educational materials for at least 12 thinking heuristics.

Case studies and research papers
Educational materials offered in the TRIZ Repository are supplemented by numerous case studies of practical application of TRIZ heuristics and research papers on TRIZ heuristics and TRIZ in general. All case studies and research papers available at the Repository have either been published or been provided by TRIZ experts and academics and approved by them for upload to the Repository. The majority of research papers are actually stored at other academic data servers (e.g. Researchgate.net). For such publications the Fellowship Repository only provide the links to the appropriate file locations. Case studies and research papers are offered in order to provide evidence of the practical value of the heuristics and to offer learners and educators examples of application of TRIZ heuristics in the engineering industry.

Educational resources
Under the ‘Educational Resources’ tab a user will find the solution templates, cheat sheets and PowerPoint files for each heuristic (also downloadable from TRIZ Tools) as well as additional educational resources and Mind Maps with methodological suggestions for learners and educators on the use of the educational resources provided by the Repository.
Figure 2 depicts an example of a Mind Map that was available from the Repository in 2017. It provided classification of the TRIZ heuristics that were already available and those that will be available in the future, explained how to use the educational materials to study heuristics in a self-learning mode, made suggestions to educators on how to introduce the heuristics in class, offered help from the Fellowship team and invited interested academics to attend the Fellowship Convention.

Figure 2. Example of a Mind Map with suggestions on how to use the TRIZ Repository

TRIZ Repository: visitors’ statistics

Prior to October 2017, statistics for the TRIZ Repository usage were collected by means of Google Analytics. From late October, statistics have been collected using both Google Analytics and Awstats – the tool offered by the private provider that hosts the Repository. Statistical data presented in this report take into account both statistical sources and cover the period from 1 December 2016 to 31 December 2017.

Since the launch of the TRIZ Repository website in December 2016, it has been visited by over 2600 users from 70 countries. These users made over 17,000 page views during just over 4000 sessions. Figure 3 presents the distribution of the number of users and the number of sessions over that period.

It needs to be noted that until November 2017 the Repository was mainly promoted to academics and students from Australia and New Zealand. Therefore, nearly two-thirds of the Repository users represented these two countries: 54.6 per cent of users came from Australia and 11.1 per cent from New Zealand. Users from the United States, India and Mexico were also in the top five, with 4.2 per cent, 3.5 per cent and 3.3 per cent of users respectively. Data in Figure 3 indicate that interest in the TRIZ Repository has grown from around 150 users a month in early to mid-2017 to around 450 users a month by the end of 2017. Traffic peaks in May and October 2017 correspond to the end of study semesters in Australia and New
Zealand. Most likely, these peaks can be attributed to students’ ‘last moment’ application of these heuristics in their university projects.

Figure 3. TRIZ Repository sessions and users: 1 December 2016 to 31 December 2017

Figure 4 presents information on the country of origin for the sessions and the device that was employed by the users to view the contents of the TRIZ Repository.

Figure 4. The distribution of the sessions per country and device (Image: Google Analytics)

The distribution of the sessions per country matches well to that for the users. Australian users had the most sessions, followed by the users from New Zealand, the United States, Mexico and India.
As shown in Figure 4, nearly 80 per cent of users viewed the Repository on their desktops and laptops. Just over 16 per cent of the sessions were on mobile phones. The remaining four per cent of sessions were on tablets. The average session lasted just over four minutes. It needs to be noted that four minutes can be considered adequate for both learners and an educators as most of the educational materials provided by the TRIZ Repository are located outside of the Repository server: short educational videos are in YouTube, research papers are in Researchgate.net and other web-based research paper repositories. Also, prior to October 2017 none of the web-based solution templates were located on a Repository server. In other words, to familiarise her/himself with the content of the Repository and to start learning the heuristics, a Repository user does not need to spend much time on the Repository site.

Sixty-seven per cent of web sessions were the result of users directly requesting the Repository site (https://edisons21.com). Twenty-nine per cent were results of user searches. The other four per cent originated from the referrals from Facebook, YouTube and XING.

Over 90 per cent of the users were operating PCs and Linux. Less than 10 per cent were using iMacs, MacBooks and iPhones.

**Promotion and dissemination**

**Face-to-face events**

The first Fellowship presentation on the need to explicitly incorporate teaching of the creativity heuristics to engineering students and to change engineering curricula was conducted on 18 October 2016 at the meeting of the Australian Council of Engineering Deans (ACED). Since then, numerous presentations have been given to academics and students at universities in Australia and New Zealand. Table 2 lists workshops, seminars and lectures facilitated by the author from October 2016 to December 2017.

<table>
<thead>
<tr>
<th>Date</th>
<th>Activity and location</th>
<th>Content</th>
<th>Attendance*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Engineering creativity and the need to update engineering curricula. Overview of Fellowship activities. Introduction to the Fellowship TRIZ Repository</td>
<td>30</td>
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<tr>
<td>17.10.16</td>
<td>Presentation to ACED, EA HQ, Melbourne Workshop, AAEE 2016 Conference, Coffs Harbour Seminar, CSU, Bathurst Seminar, UTS, Sydney Seminar, WSU, Parramatta Seminar, RMIT, Melbourne</td>
<td>Engineering creativity and the need to update engineering curricula. Overview of Fellowship activities. Introduction to the Fellowship TRIZ Repository</td>
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<tr>
<td>17.02.17</td>
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<td>Overview of Fellowship activities. Introduction to the Fellowship TRIZ Repository</td>
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</table>
Table 2 (continued). Events facilitated by the Fellow (*approximate numbers)

<table>
<thead>
<tr>
<th>Date</th>
<th>Activity and location</th>
<th>Content</th>
<th>Attendance*</th>
</tr>
</thead>
<tbody>
<tr>
<td>08.03.17</td>
<td>Lecture RMIT, Melbourne</td>
<td>Lecture on engineering creativity and thinking heuristics provided by the Fellowship TRIZ Repository</td>
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<tr>
<td>22.03.17</td>
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<td>Lecture on engineering creativity and thinking heuristics provided by the Fellowship TRIZ Repository</td>
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<tr>
<td>28.03.17</td>
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<td>Overview of Fellowship activities. Introduction to the Fellowship TRIZ Repository</td>
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<tr>
<td>29.03.17</td>
<td>Lecture, UoA, Auckland</td>
<td>Lecture on engineering creativity and thinking heuristics provided by the Fellowship TRIZ Repository</td>
<td>500</td>
</tr>
<tr>
<td>29.03.17</td>
<td>Seminar, UoA, Auckland</td>
<td>Overview of Fellowship activities. Introduction to the Fellowship TRIZ Repository</td>
<td>50</td>
</tr>
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<td>29.03.17</td>
<td>Discussion, UoA, Auckland</td>
<td>Academic discussion on the ways and the means to enhance creativity skills of engineering graduates</td>
<td>9</td>
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<tr>
<td>30.03.17</td>
<td>Lecture, UoA, Auckland</td>
<td>Lecture on engineering creativity and thinking heuristics provided by the Fellowship TRIZ Repository</td>
<td>60</td>
</tr>
<tr>
<td>13.07.17</td>
<td>Presentation UTas, Hobart</td>
<td>Overview of Fellowship activities. Introduction to the Fellowship TRIZ Repository</td>
<td>17</td>
</tr>
<tr>
<td>09.08.17</td>
<td>Presentation, ANU, Canberra</td>
<td>Overview of Fellowship activities. Introduction to the Fellowship TRIZ Repository</td>
<td>18</td>
</tr>
<tr>
<td>09.08.17</td>
<td>Seminar, ANU, Canberra</td>
<td>Overview of Fellowship activities. Introduction to the Fellowship TRIZ Repository</td>
<td>12</td>
</tr>
<tr>
<td>19.10.17</td>
<td>GK Reception RMIT, Melbourne</td>
<td>Introduction to the Fellowship TRIZ Repository to new RMIT members of the Golden Key International Honour Society</td>
<td>250</td>
</tr>
<tr>
<td>22.11.17</td>
<td>IEEE presentation, Melbourne</td>
<td>First outcomes of Fellowship activities</td>
<td>4</td>
</tr>
<tr>
<td>11.12.17</td>
<td>Workshop, AAEE 17, Manly, Sydney</td>
<td>Discussion on the need of engineering curriculum to enhance creativity (included presentations of three student winners of the Edisons21 Creativity Challenge)</td>
<td>41</td>
</tr>
<tr>
<td>12.12.17</td>
<td>Special sessions, AAEE 17, Manly, Sydney</td>
<td>Three research paper sessions devoted to engineering creativity. Seventeen papers have been presented by participants from nine countries</td>
<td>94</td>
</tr>
<tr>
<td>14.12.17</td>
<td>Presentation to engineering Deputy/Associate Deans (Education), Sydney</td>
<td>Short report on Fellowship activities in 2016-17, future plans and help expected from Deputy/Associate Deans</td>
<td>21</td>
</tr>
</tbody>
</table>

The need to engage engineering students in upgrading their creativity skills and to appropriately adjust engineering curricula was also raised at presentations of the members.
of the Fellowship Expert team and colleagues from the Engineers Without Borders (EWB) Australia and the Golden Key International Honour Society, which cooperated closely with the Fellowship team.

Four presentations were given by the members of the Fellowship Expert team. Associate Professor Bohuslav Busov conducted a seminar on TRIZ creativity heuristics at The University of Western Australia (UWA) (05 December 2017, Perth). Professor Gaetano Cascini presented to RMIT academics on his work on creativity funded by grants from the European Union and reflected on the first outcomes of the Fellowship activities (07 December 2017, Melbourne). Professor Leonid Chechurin provided insights on application of TRIZ heuristics in research with academics and research students from the electrical engineering discipline (08 December 2017, Melbourne). Professor Pavel Livotov shared his experience of teaching TRIZ heuristics in Germany with the members of Victorian Chapter of IEEE (18 December 2017, Melbourne).

Dr Nick Brown from EWB Australia promoted the TRIZ Repository to academics and students during his talks at the Australian National University (27 February 2017, Canberra), The University of Queensland (08 March 2017, Brisbane), RMIT (10 March 2017, Melbourne), The University of Sydney (14 March 2017, Sydney), The University of Adelaide (16 March 2017, Adelaide), and Curtin University (06 April 2017, Perth).

Altogether, over 400 academics and more than 1300 engineering students attended the face-to-face Fellowship events.

**Promoting the Fellowship electronically**

**Email and web promotion**
From mid-December 2016, the Fellowship team sent emails to Deputy/Associate Deans (T&L), engineering academics and engineering students suggesting the use of the educational materials from the TRIZ Repository for teaching and for self-learning. In order to reach more students the Fellowship team established close relationships with professional and student associations. Our relationships with EWB Australia and the Golden Key International Honour Student Society (Golden Key) alone helped to promote the Fellowship activities and the TRIZ Repository to over 6000 Australian students.

EWB Australia is a member-based, not for profit, community organisation that creates social change through engineering. Education is a major aspect of EWB Australia's work it supports a number of programs, including the EWB Challenge, the EWB Design Summits and the Humanitarian Research Program. The EWB Challenge, which is sponsored by BHP Billiton, involves over 8,000 Australian engineering students from 33 Australian universities each year. In 2017, the educational resources of the TRIZ Repository were promoted to students and academics via links to the Repository on the EWB website and by direct emails to coordinators of all Australian engineering courses that participated in EWB programs. Figure 5 shows one of the links to the Fellowship Repository at the EWB Australia website that was created in February 2017.
Golden Key is the world’s largest collegiate honour society. Membership of the Society is by invitation only and applies to the top 15 per cent of students in all fields of study, based solely on their academic achievements. Golden Key has more than 400 chapters at colleges and universities around the world and unites more than 2.2 million members. Australian membership is the second largest outside the United States of America. Dame Quentin Bryce, General Sir Peter Cosgrove and Ian Thorpe are some of the honorary members of Golden Key in Australia. In 2017, the educational resources of the Repository were promoted to the Golden Key members via links to the Repository on the Golden Key website and by direct emails to Australian Golden Key members.

Promotional video
In order to engage international academics and TRIZ experts in Fellowship activities, a two-minute video was recorded in July 2016. The video explained the goals of the Fellowship and asked international experts to support the Fellowship team by providing advice, educational materials, research papers and case studies for inclusion in the Fellowship Repository. The video was provided to the 2016 organisers of two conferences that usually attract the majority of the world TRIZ practitioners and interested academics: the 12th International TRIZfest-2016 (held in Beijing, People’s Republic of China, from 28 to 30 July 2016) and the 16th International Conference of the European TRIZ Association (ETRIA) (held in Wroclaw, Poland, from 24 to 27 October 2016). As a result, numerous TRIZ experts offered the Fellowship team additional resources for inclusion into the TRIZ Repository.

Edisons21.com Creativity Challenge
To ensure that more students learn effective thinking heuristics and are able to apply these heuristics in their university projects, the Fellowship team invited Australian students to participate in the Edisons21.com Creativity Challenge. An invitation to participate in the Challenge was emailed to students via EWB Australia, Golden Key and the IEEE. Numerous Deputy/Associate Deans (T&L) and Australian engineering academics were asked to pass the
invitation on to their students. This announcement was also available from the TRIZ Repository website. The announcements were made in mid-May 2017 with the submission date being 1 November 2017.

In order to participate in the Challenge, students had to prepare a report that contained information on (i) their project/task, (ii) the application of TRIZ heuristics to this project, (iii) the outcomes of that application (sketches, photos and even videos) as well as (iv) their reflections on how and why these heuristics helped them in project work. Students were also asked to reflect on their experiences of learning creative problem solving at university and to outline the steps needed ensure the engineering graduates of the 21st Century will gain skills in creative problem solving aligned with the demands of the job market of the future.

Fifty-four students registered for the Challenge. The three winners, representing UWS, RMIT and UNSW, were invited to participate in the Fellowship Convention and to present at the Fellowship workshop held in Sydney in December 2017.

**Fellowship Convention**

The Fellowship Convention occurred at the conference of the 2017 Australasian Association for Engineering Education (AAEE 2017) in Sydney from 10 to 13 December 2017. The Convention consisted of the special conference focus session titled ‘Educating the Edisons of the 21st Century: integrating thinking heuristics (including TRIZ) into the engineering curriculum’ and the Fellowship workshop titled ‘Integrating Creativity Into Curriculum: Let Us Listen To Students’. The Fellowship Convention was widely promoted by the Fellowship team in Australia and overseas. Many local and international academics and TRIZ practitioners were invited to prepare papers and to attend the Convention.

**Edisons21 Session**

The Fellowship focus session attracted 17 research presentations by academics and practitioners from nine countries: Australia, Italy, Finland, the Czech Republic, the Russian Federation, the Netherlands, New Zealand, China and Germany. All five members of the Fellowship Expert team attended the Convention and presented their research papers. Mr Christoph Dobrusskin from Philips, The Netherlands, and a member of the Fellowship Reference Group also presented his paper. Figure 6 depicts the session flyer – including the titles of all research presentations related to engineering creativity – that was emailed to numerous academics and engineering professionals in Australia and overseas.

This flyer was also printed and used at the AAEE 2017 conference venue to attract more conference participants to the Fellowship Convention. The special session was attended by nearly 100 conference participants and generated numerous discussions at and outside the session venue. It presented a good overview of teaching thinking heuristics in Europe and China and further highlighted the importance of explicit incorporation of teaching creativity heuristics into Australian engineering curricula.
Although all 17 research papers presented at the session were related to development of students’ creativity skills, two papers were specifically devoted to the outcomes of utilisation of the educational materials provided by the TRIZ Repository. Mr Aaron Blicblau from Swinburne University presented on the positive influence of the Size-Time-Cost Operator heuristic on decisions by project teams of the first-year students on the choice of materials to build various engineering structures. Konstantin Shukhmin from Toi-Ohomai Institute of Technology (New Zealand) shared the first outcomes of teaching the Eight Fields of MATCEMIB, Size-Time-Cost Operator and Ideal Ultimate Result heuristics on students’ project ideas.

Edisons21 workshop
At the beginning of the workshop, the three student winners of the Edisons21.com Creativity Challenge (representing WSU, UNSW and RMIT) shared their stories on how they have learned thinking heuristics from the TRIZ Repository and applied these heuristics in their university projects/activities. Students also reflected on the effectiveness of their university programs in enhancing their creativity skills. Figure 7 shows a photograph taken during a presentation of one of the winners of the Edisons21.com Creativity Challenge at the Fellowship workshop.
After the student presentations, the workshop participants, together with students and international guests from Italy, Finland, Germany, Russia, China, Czech Republic, the Netherlands, China and New Zealand were involved in a discussion on the most suitable means to engage engineering students in enhancing their thinking skills. With the help of engineering students, the participants were able to brainstorm ways to embed learning creativity skills into existing engineering courses and the actions needed for integration of creativity heuristics into engineering curricula.

The Fellowship workshop was well attended and helped to engage not only engineering educators but also representatives of Engineers Australia in important discussions on the future of the engineering profession and the requirement for enhancing engineering curricula to ensure sound creativity skills among Australian engineering graduates.

**Additional promotion**

In order to further promote the Fellowship Repository and to familiarise more engineering educators with TRIZ heuristics, the Fellowship team created business card-sized double-sided promotion cards, on one side showing the steps of a TRIZ heuristic and on the other side a link to the Fellowship Repository. Promotion cards for the heuristics of the Eight Fields of MATCEMIB and the Size-Time-Cost Operator were printed. Figure 8 depicts the promotion card for the Size-Time-Cost Operator heuristic.
Over 300 promotional cards were distributed to the participants of the AAEE 2017 conference.

**Presentation to Engineering Deputy/Associate Deans (ADTL)**

On 14 December 2017, after the AAEE 2017 conference, I presented at a meeting of Australian Deputy/Associate Deans (ADTL). This presentation was devoted to the Fellowship activities over 2016–17 and provided the Deputy Deans with an overview of future activities and support available in 2018 for academic leaders and academic staff to embed heuristics into engineering courses effectively.
Chapter 5: First Outcomes and Reflections

Overall, the Fellowship activities achieved the original goal and were able to raise awareness among Australian engineering Deans and Deputy/Associate Deans of the need to revisit engineering curricula and to devote more attention to development of student creativity skills over the four years of an engineering degree.

Utilisation of education materials of the TRIZ Repository

Educators representing CSU, RMIT, Swinburne University, The University of Melbourne, Western Sydney University, UTS, UNSW, The University of Auckland, Auckland University of Technology and Toi-Ohomai Institute of Technology (New Zealand) introduced students to TRIZ heuristics. Academics from Swinburne University and Toi-Ohomai Institute of Technology have also reported on the outcomes of exposing their students to TRIZ heuristics. This section of the Fellowship Report is based on the findings published by Blicblau and Ang (2017) and Shukhmin and Belski (2017). These studies were conducted in Semester 1, 2017, and are summarised in the section following.

Swinburne University of Technology study

One hundred and ten students who were enrolled in the first-year Engineering Materials course participated in Blicblau and Angs study (2017). During one of the course laboratories, conducted in a blended learning mode (no face-to-face contact with laboratory tutors), students were asked to select materials to build various engineering structures, such as bridges, homes or hand-tools. Students were minimally briefed and had to rely on the knowledge acquired at secondary school. After students made their decisions on the materials for manufacturing the structures, they were asked to learn the Size-Time-Cost (STC) Operator heuristic and to repeat the exercise of material selection. The authors reported on significant differences in subsequent choices of materials made by the students that can only be explained by the use of the STC Operator heuristic:

When students responded to the first engineering activity for realistic solutions to the materials selection problems, they all selected either one of two classes of materials for the engineering components, i.e. metals (e.g. varieties of steel, aluminium, or composites) … When students were asked to … [use] the TRIZ (STC) approach … a variety of traditional (steel, aluminium and wood) and non-traditional materials (titanium, carbon nanotubes, graphene, diamond, ceramics, and gold) were selected for the various constraints. (Blicblau & Ang, 2017, p. 754)

The authors concluded that the STC Operator heuristic helped students look beyond traditional engineering techniques and consider novel materials and manufacturing techniques:

The conclusions of this activity are that giving students constraint-free activities often resulted in uncommon solutions to engineering materials selection problems, whilst keeping in mind that standard solutions were also applicable. (Blicblau & Ang, 2017, p. 756)
While presenting the study results at the Fellowship Convention, Mr Blicblau mentioned that the influence of such simple heuristics as the STC Operator on students' material choices was unexpectedly positive and that it really helped students to expand their view of the materials available to manufacture various structures. Mr Blicblau subsequently embedded this heuristic into the Engineering Materials course for 2018 and is also considering using this heuristic – as well as other heuristics offered by the TRIZ Repository – in other courses he coordinates.

It is important to note that while application of the STC Operator heuristic was not compulsory and did not influence the grade awarded, the majority of students enrolled in the course did use the heuristic and were enthusiastic about the outcomes it helped them to produce.

Toi-Ohomai Institute of Technology study

Sixty students enrolled in various diploma programs at Toi-Ohomai Institute of Technology (TOIT) were introduced to three TRIZ heuristics in Semester 1, 2017 (Shukhmin & Belski, 2017). Students were a mix of school leavers and mature-age students and represented both first-year and the second-year (graduating) student cohorts.

Three class sessions on TRIZ heuristics were conducted. The first and third sessions were very similar. The first session engaged students enrolled in their last year of study, the third session the first-year students. At these sessions, students were introduced to TRIZ heuristics of Eight Fields of MATCEMIB and STC Operator. This was done in accordance with the recommendations provided by the Fellowship Repository. The second session was conducted for the students of both years of study enrolled in the diploma of mechanical engineering. This session was devoted to the Ideal Ultimate Result (IUR) heuristic. At the end of each session, students were asked to consider investing their own time in learning more TRIZ heuristics directly from the Repository. Graduating students were also encouraged to use TRIZ heuristics in their final-year engineering projects and to incorporate solution templates into their final project reports.

The authors of the study report the heuristics’ positive influence on idea generation in class:

After watching the video on the 8 Fields of MATCEMIB heuristic, participants of the first and the third sessions proposed many more ideas for building protection against termites. In essence the number of solution ideas doubled as a result of them watching the video. (Shukhmin & Belski, 2017, p. 233)

They also note that individual students had different interest in learning TRIZ heuristics:

Student reaction to TRIZ heuristics varied from full support to absence of any interest. Some were very excited and said that they will try applying the heuristics to their own ‘world saving’ inventions; some were simply bored. Students from mechanical and electrical streams were much more engaged in class activities than that of the civil discipline. Mature students were much more interested than recent school leavers and were willing to immediately apply TRIZ heuristics to solve their problems. (p. 233)
Reflecting on the outcomes of the study, the authors conclude that the most likely reason for student reluctance to engage in learning TRIZ heuristics was related to absence of formal assessment of activities associated with learning these heuristics. Shukhmin and Belski suggested that it was also possible that ‘some final-year students hesitated to use the heuristics because they have had ideas on conducting their project work already and were unwilling to make changes to the ideas that they have developed prior to learning the heuristics’ (p. 235).

Twenty-one TOIT students participated in a survey conducted a few months after they were introduced to the TRIZ heuristics in class. Most of the survey participants confirmed that they had devoted their own time and studied more TRIZ heuristics from the Fellowship Repository on their own. They also assessed the educational materials provided by the Repository as fully suitable for self-learning and useful in their future career (Shukhmin & Belski, 2017). Furthermore, as became clear at the end of Semester 2, 2017, four graduating students incorporated the outcomes of their application of the TRIZ heuristics into their final project reports.

Survey results

The Fellowship team developed and administered web-based surveys to students and academics who utilised the TRIZ Repository in 2017. Both surveys were built in Qualtrics. Survey links were sent to academics who introduced TRIZ heuristics to their students, student participants of the Edisons21.com Creativity Challenge and officers from EWB Australia and Golden Key who had supported the Fellowship activities.

Student surveys

Student surveys consisted of 57 questions and required 20–30 minutes to complete. Survey questions were designed to collect basic information about students and their field of study, their perceptions on their own creativity skills and their opinions of the heuristics offered by the Fellowship Repository. Some questions required written entry from students. Fifty-eight students participated in the survey, and 39 completed it.

Quantitative data

Table 3 depicts the responses of the students to questions related to the quality and suitability of self-educational materials available at the TRIZ Repository.

Overall, students evaluated educational materials provided by the Fellowship Repository as appropriate for self-learning. Students assessed short videos as ‘good’ for explaining the application of heuristics. PDF solution templates (3.87/5) and cheat sheets (3.90/5) were judged as appropriate application guides. Web-based solution templates were evaluated a little less positively than PDF templates. The student opinions presented in Table 3 on the educational resources provided by the TRIZ Repository clearly support the suitability of these materials for self-leaning.
Table 3: Students’ opinions on the usefulness of educational materials offered by the TRIZ Repository. All questions used a Likert scale (1 = strongly disagree; 5 = strongly agree)

<table>
<thead>
<tr>
<th>Educational materials for self-learning TRIZ heuristics made it easy for me to learn thinking heuristics</th>
<th>A short video that explained the way to apply a heuristic...</th>
<th>A solution template that guided me in applying a heuristic for the first time...</th>
<th>A web tool that guided me in applying a heuristic for the first time...</th>
<th>A cheat sheet was very helpful in learning the heuristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean 3.97</td>
<td>3.92</td>
<td>3.87</td>
<td>3.61</td>
<td>3.90</td>
</tr>
<tr>
<td>SD 0.577</td>
<td>0.640</td>
<td>0.629</td>
<td>0.722</td>
<td>0.712</td>
</tr>
</tbody>
</table>

Survey participants were also asked about the influence of learning TRIZ heuristics on their abilities to frame problems and generate ideas and about changes in their problem-solving approach as a result of learning these heuristics. Student responses to these questions are presented in Table 4.

Table 4: Students’ opinions on the influence of TRIZ heuristics. All questions used a Likert scale (1 = strongly disagree; 5 = strongly agree)

<table>
<thead>
<tr>
<th>I believe the heuristic(s) I have learned helped me to understand my problem much more clearly</th>
<th>I believe the heuristic(s) I have learned helped me to generate more ideas for my project</th>
<th>Learning the heuristics changed the way I resolve problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean 3.88</td>
<td>3.79</td>
<td>3.65</td>
</tr>
<tr>
<td>SD 0.537</td>
<td>0.592</td>
<td>0.597</td>
</tr>
</tbody>
</table>

Again, student opinions on the influence of TRIZ heuristics presented were positive. More specifically, two skill areas found to most strongly influence engineering creativity skills were addressed by the heuristics available at the Fellowship Repository. First, students agreed that the heuristics they have learned helped them in problem finding (3.88/5). Second, they have reported that TRIZ heuristics helped them generate more ideas (3.79/5). It is also interesting to note that student responses to the last statement in Table 4 (Learning the heuristics changed the way I resolve problems) indicated a more profound influence of heuristics on student problem-solving skills. It is too early to consider their perceptions as a definite change in problem-solving approaches; nonetheless, a slightly positive answer to the last question in Table 4 confirms the ability of TRIZ heuristics to be easily remembered and to positively influence student cognition strategies.

Additional comments from students that support the suitability of the educational materials for student self-learning and the effectiveness of these heuristics in guiding undergraduate students to novel solutions are presented in the Appendix C.
Academic survey

The survey of academics contained 32 questions and required 15–20 minutes to complete. The survey contained questions focused on general information as well as questions related to the suitability of educational materials provided by the Fellowship Repository for embedding into existing discipline subjects. Four academics completed this survey.

Quantitative data

Table 5 depicts the opinions of the surveyed academics on suitability of heuristics offered by the Fellowship Repository for embedding into the existing courses they teach.

Table 5: Educators’ opinions on the usefulness of educational materials offered by the Repository. All questions used a Likert scale (1 = strongly disagree; 5 = strongly agree)

<table>
<thead>
<tr>
<th>Educational materials offered by the TRIZ Repository are useful for my students</th>
<th>Educational materials offered by the TRIZ Repository can be easily embedded in my subject</th>
<th>I could use the educational materials offered by the TRIZ Repository with minimal adjustment (minimal time investment)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>4.25</td>
<td>3.75</td>
</tr>
<tr>
<td>SD</td>
<td>0.500</td>
<td>0.500</td>
</tr>
</tbody>
</table>

Responses from all four academics, who had engaged their students in learning TRIZ heuristics from the Fellowship Repository, are well aligned. The results show that (i) educational materials provided by the Repository can be embedded into (at least some) existing discipline courses, (ii) the materials will not require significant adjustment, and (iii) these TRIZ heuristics will be useful to students.

Academic participants of the survey were also asked to assess the quality of materials for self-learning provided by the Fellowship Repository. Table 6 presents these opinions.

Table 6: Educators’ opinions on the usefulness of TRIZ heuristics. All questions used a Likert scale (1 = strongly disagree; 5 = strongly agree)

<table>
<thead>
<tr>
<th>A short video that explained the way to apply a heuristic...</th>
<th>A solution template that guided me in applying a heuristic for the first time...</th>
<th>A web tool that guided me in applying a heuristic for the first time...</th>
<th>A cheat sheet was very helpful in learning the heuristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>4.00</td>
<td>4.50</td>
<td>3.75</td>
</tr>
<tr>
<td>SD</td>
<td>1.000</td>
<td>0.577</td>
<td>1.258</td>
</tr>
</tbody>
</table>

The responses in Table 6 support those of the students presented in Table 3 and confirm the suitability of educational materials developed by the Fellowship team. Heuristic cheat sheets and PDF solution templates were rated very highly by educators. Short videos were assessed as explaining the solution processes well. It was only on the web-based template that
educator views diverged slightly; one respondent thought the web-based template was not useful, while the other three found it useful.

Comments from educators

Educators also reflected on a number of issues related to the use of TRIZ heuristics in engineering education. Some comments from academics that supplement their quantitative responses to the statement, ‘Educational materials offered by the TRIZ Repository are useful for my students’ presented in Table 5 are provided in the Appendix D.

Reflections of the winners of the Edisons21.com Creativity Challenge

All three winners of the Challenge reflected on learning and application of TRIZ heuristics. They also made suggestions on improvement of engineering curriculum. Although the winners represented different universities, their reflections were similar. The Appendix E presents the reflections of one of the winner.

Impact of Fellowship activities

The fifteen months of the Fellowship activities influenced the Fellowship team, engineering educators and engineering students.

The Fellowship activities helped many engineering educators and engineering students discover the work on engineering creativity carried out by the Fellow and the Fellowship team. This was achieved by launching the TRIZ Repository, conducting face-to-face presentations and seminars, running electronic promotions and bringing international experts in TRIZ education to the Fellowship Convention and putting them in direct contact with hundreds of engineering educators who attended the AAEE 2017 conference.

In 2017, academics from six universities in Australia and New Zealand tried to embed TRIZ heuristics into their courses. Academics from The University of Melbourne, RMIT, Swinburne University of Technology, CSU, WSU and TOIT subsequently embedded TRIZ heuristics into their discipline courses in 2018. Changes in curriculum to focus on developing creativity skills in engineering graduates have been considered by the engineering schools at RMIT, WSU, CSU and The University of Melbourne.

Thousands of engineering students from Australia and New Zealand have been informed of the TRIZ Repository. Many of them have learned TRIZ heuristics and successfully used these heuristics in developing ideas for their university projects. This was achieved promoting the Repository to engineering academics and engineering students in Australia and New Zealand, conducting the Edisons21.com Creativity Challenge and supporting academics who introduced TRIZ heuristics to students in 2017.

Knowledge of the TRIZ Repository was spread by means of peer-review publications, presentations at conferences and universities, workshops, promotional videos and the help of emails and web links. Six peer-reviewed papers on the Fellowship activities were published in 2017. A book chapter and four peer-reviewed papers were published in 2018.
Edisons21.com: Where next?

Although the Fellowship activities achieved the original goal and raised awareness among Australian engineering Deans, Deputy/Associate Deans and engineering academics of the need to revisit engineering curricula and to devote more attention to development of student creativity skills over the four years of an engineering degree, it is only the first step on the path to educating truly creative engineering graduates. Academics need not only to acknowledge the importance of creativity skills for the engineering graduates of today and tomorrow but also to take action and change engineering curricula accordingly. This will not happen overnight; it will require several more years of engaging academics in introducing creativity heuristics to students, collecting evidence of student successes, sharing the evidence with community of engineering educators and helping them embed the heuristics into their discipline courses.

It is anticipated that Engineering Deans will be updated by the Fellow of the first outcomes of the Fellowship at the ACED meeting that will be held at the World of Engineering Convention (Melbourne, November 2019). In 2016, the Fellow presented Deans with the Fellowship plans and argued that the TRIZ heuristics would suit engineering academics. Following the Fellowship activities, the Fellow will present evidence that TRIZ heuristics have worked as way anticipated and that the educational materials provided by the Fellowship Repository suited both students and academics.

The Fellowship team will continue close cooperation with EWB Australia and Golden Key in order to engage more students in self-learning of creativity heuristics. Edisons21 Creativity Challenge of 2019 is under preparation. The 2020 Challenge is under consideration.

As planned, the Fellow together with the Fellowship Expert Team will continue to update the TRIZ Repository. It is envisaged that educational materials for at least 12 TRIZ heuristics will be available from the Repository by 2019. The Fellowship team also hopes to develop more electronic resources (e.g., an app for every heuristic).

Further studies on application of educational materials offered by the Fellowship Repository will be conducted. In 2018 the impact of TRIZ heuristics was investigated by academics at RMIT, The University of Melbourne, Swinburne University, The Polytechnic University of Milan, and at the Toi-Ohomai Institute of Technology. The outcomes of the studies at RMIT and The University of Melbourne were published. More papers will be published in academic journals and promoted to ACED, ADTL, Australian engineering academics, as well as at conferences locally and internationally.

Promotion of the Repository and the importance of teaching creativity skills explicitly will continue via academic publications and presentations. The Fellow plans to share the outcomes of Fellowship activities with academics beyond engineering. Many heuristics offered by the Repository are weak (e.g., STC Operator, IUR, Situation Analysis) and can be used practically in any field of human activity. The Fellowship Impact Plan is presented in Table 7 (see Appendix E).
Appendix A

Certification by Deputy Vice-Chancellor

I certify that all parts of the final report for this OLT fellowship provide an accurate representation of the implementation, impact and findings of the project, and that the report is of publishable quality.

Name: Professor Belinda Tynan                                Date: 17 February 2018
Appendix B

Fellowship Evaluation Report

Professor Roger Hadgraft
Director, Educational Innovation and Research
University of Technology Sydney
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Educating the Edisons of the 21st Century: embedding tools of the Theory of Inventive Problem Solving (TRIZ) into the engineering curriculum

Summary
This has been a very well executed Fellowship; it has delivered on all of its objectives, as described below.

Professor Belski set out to provoke engineering educators to include creativity heuristics in their teaching. He has delivered numerous workshops and presentations, developed a website of resources with his international collaborators, run a national student competition, and a mini-conference at our national engineering education conference in December 2017. Several academics from other universities have joined him in researching the induced improvements in student creativity.

This report takes the original Objectives and Deliverables from the project plan and evaluates achievements against each of them. Comments later consider the process as it evolved through our many conversations, which might be helpful for any future Fellowships.

What was proposed
Fellowship objective
By means of constructing and promotion of a web-based repository of TRIZ (Theory of Inventive Problem Solving) educational materials, this Fellowship will initiate and lead change in engineering curricula that will enable Australian engineering educators to eliminate the existing gap in generic skills between Australian 15 year olds and their Asia Pacific counterparts and will ensure Australian engineering graduates possess the most advanced generic skills of creative problem solving.

Professor Belski and his team have delivered on his promise ‘to initiate and lead change in engineering education’, by equipping Australian engineering graduates with explicit creativity skills for a world where the pace of innovation seems to be accelerating, driven by exponential growth in computing capacity.

To achieve the grand objective of making sure that Australian engineering graduates have advanced skills in creative problem solving, we will have to see more widespread change in
the structure of engineering curricula. Students need scope for creativity, unlike current curricula, which are focused on students learning existing solutions to existing problems.

**Fellowship deliverables**

*This Fellowship will:*

*a) Integrate existing educational resources that have been developed so far by leading world academics who have introduced TRIZ at their universities.*

Professor Belski has successfully engaged his international TRIZ network to bring together a range of resources at the edisons21.com website. These resources are now available to all engineering schools and workshops have been run for many of them. Several universities will use the TRIZ techniques in 2018, as we have done at UTS in our Summer Studios.

*b) Develop a web-based repository of TRIZ educational materials (under Creative Commons) that could be embedded into existing engineering units and used by individual students for self-learning. This repository will contain teaching materials, implementation guides for teachers, self-study guides for learners as well as industry case studies that illustrate the application of TRIZ tools.*

The website (see chapter 4) collects together resources for 7 of the TRIZ creativity heuristics at this point in time (Feb 2018), with several more to be included in the next 12–24 months.

The resources include self-learning materials, such as short videos, instruction sheets, templates for implementing the technique, and research papers to support the efficacy of the technique. The research has shown that students easily use these resources to enhance the idea generation capability.

*c) Promote the web-based repository of TRIZ teaching materials to Australian engineering academics with help from professional associations, engineering deans and TRIZ enthusiasts.*

This has been an area of very significant activity by Prof. Belski. As the report shows, there have been more than a dozen workshops at as many universities, involving more than 400 academics. The mini-conference at AAEE 2017 in Sydney, provided opportunity for another 250 academics to get involved, through three paper sessions including a workshop.

*d) Engage students enrolled in engineering degrees in Australia in utilising TRIZ tools in their projects with help from student associations and non-for-profit organisations.*

Students have been explicitly engaged through associations such as Engineers Without Borders (the widely used first-year EWB Challenge) and the Golden Key Honour Society so that more than 6000 students were made aware of the creativity resources. The national student challenge brought some of those examples to the AAEE 2017 conference, where we were able to see the impact of students’ increased creativity capabilities.

*e) Engage Australian engineering academics in introducing students to the basic tools of TRIZ and offer appropriate support to these academics.*
See information under (c) above.

f) **Initiate a community of TRIZ adopters at Australian engineering faculties and connect Australian academics with the international academic community that teaches TRIZ and uses it in research.**

Some of the academics involved in the workshops worked with Prof. Belski on deeper engagement with the TRIZ techniques, as evidenced by papers published and included in this report. Key findings are discussed in chapter 5 of the report, with students reporting increased capability to develop new ideas with the aid of the heuristics.

A key outcome of the special sessions at the AAEE 2017 conference was the opportunity for those academics, and others who attended (more than 50 at the sessions), to meet and discuss the techniques and their application with the five visiting international experts, all of them with long engagement in TRIZ techniques.

Development of the community has been slower than expected. However, there is already activity at Swinburne University, The University of Melbourne and the Toi-Ohomai Institute of Technology (NZ) and RMIT, of course, with papers published with the Fellowship team. These activities are now successfully embedded in specific classes at each university, with clearly positive outcomes for students. EWB will continue to promote TRIZ through the Challenge in 2018.

With the support of the AAEE community, it is reasonable to expect that a dedicated TRIZ session could run at the conference each year for the next several years at least. Innovation will continue to grow in importance for industry during that time and changes to curricula will be necessary to support it (e.g., more open-ended design tasks). The availability of these heuristics provides one set of resources to support more open-ended, project-based learning in engineering.

g) **Disseminate the outcomes of the Fellowship at conferences and in peer-reviewed publications.**

Seven papers have been published in conjunction with the Fellowship, as listed in Appendix C. The mini-conference at AAEE 2017 was a standout event, bringing together international experts to discuss the techniques and provide examples from some of the biggest companies in the world, e.g. Samsung, where these techniques are a part of standard engineering practice. I would like to see similar sub-events at future AAEE conferences, on important topics, such as this one.

**Timeline**

*The Fellowship activities will be conducted over 15 months: from 1 October 2016 to 31 December 2017.*

The Fellowship activities were completed within this timeframe, with report writing in January and February 2018.

**Post Fellowship activities: from January 2018**

*Activity 4 will continue after conclusion of the proposed 15 months of the Fellowship. Educational materials for the five tools that Table 1 proposed for postgraduate students will be uploaded to the Fellowship website by December 2019. In order to ensure that adoption*
of TRIZ tools into engineering curricula will become sustainable, promotion of the Fellowship Repository and successes of TRIZ application by engineering students and academics will continue for another three to five years.

Work on the website is continuing, with several additional techniques to be posted during 2018/19.

There is an opportunity here for Prof. Belski to build a community of practice around the TRIZ techniques, using some of the early adopters in Melbourne, in particular, as leaders in that community. Members of the AAEE community will be supporters in this process.

Comments on process
Reviewing my notes from our regular Skype conversations, it is easy to see why the Fellowship has successfully delivered on its objectives.

- In September 2016, we discussed the website, a key outcome of the Fellowship. By that stage, Iouri already had the basic site operational, with the menu bar setup, ready to be populated and a mindmap showing the overall structure planned for the website. He was then working on the first of the heuristics.
- Engagement with EWB and the Golden Key Society was also underway. We discussed the possibilities for including TRIZ in the curriculum, e.g. at UTS, we could develop a module for our students on internships.
- Iouri was invited to speak at ACED in October 2016. As a result, invitations were received from several Deans for workshops at their universities – UTS, Swinburne, CSU, UTas, CDU, Curtin, WSU.
- The video for MATCEMIB was reviewed and feedback given in October.
- Jan–Feb 2017 – several workshops were run at universities, with Auckland in March.
- Through 2017, there was busy activity on several fronts, including conducting the studies of student creativity included in the report, writing the resulting papers, developing the resources for the heuristics and organising the mini-conference for Dec 2017 – inviting the international experts, reviewing papers, etc.

In summary, this Fellowship has been successfully planned and executed from the very beginning, helped by a speedy launch. Establishing the website early, the central activity of the Fellowship, with a well thought-through structure, meant that the resources could be added incrementally, and the workshops could also get off to a quick start (Jan–Feb 2017, before semester started at most places). These continued through 2017 and culminated in the activities at AAEE in December. Professor Belski’s wide international network of experts has also meant easy access to resources and examples, for inclusion on the website.
Appendix C

TRIZ Repository: Student comments

Below are some of the comments from students that support the suitability of the educational materials for student self-learning and the effectiveness of these heuristics in guiding undergraduate students to novel solutions.

The following are student responses to the statement, ‘Educational materials for self-learning TRIZ heuristics made it easy for me to learn thinking heuristics’.

*It’s a clear-cut process to follow, easy to understand and implement.*

*Learning how to use thinking heuristics was very easy and understandable using the educational materials.*

*I found the process easy to follow and implement on my project, it’s a great way of thinking different about a project.*

*The use of the self-learning templates made it easy to keep on the right direction when a broader sort of thinking was required for my project. It has helped me think outside the box whilst still achieving my intended goals.*

*I found it pretty easy to read and understand the concepts.*

*I used the cheat sheet and the template for the STC. They were useful to guide me through the steps of thinking.*

*The materials provided a good explanation and description that was easy to follow.*

The following are student responses to the statement, ‘I believe the heuristic(s) I have learned helped me to understand my problem much more clearly’.

*Heuristics techniques helped me see problems from all directions and to think outside the box.*

*It makes you think in different ways you would not usually think’*

*Because I was able to approach the problem from many different angles I got new ideas that helped me a lot to solve the problem.*

*It helped narrow the problem down into categories that have viable solutions’. ‘Helped to look at the bigger picture.*

*Being able to see problems from more than one angle.*

*They helped me think of my problem from different angles which stopped me from being closed minded while solving my problem.*

*Applying different constraints in the STC, helped me to think about the conditions that lead to the problem that I am trying to solve.*

*It helps you to have a better overview of the problem.*
Doing the project, you face a ton of problems, and this helps to approach the problem at different angles.

The following are student responses to the statement, ‘I believe the heuristic(s) I have learned helped me to generate more ideas for my project’.

*I’m very experienced with creative problem solving and lateral thinking, accompanied by industry knowledge. Applying heuristics has reinforced my current methodology and generated few new ideas.

Using the heuristics, I was able to find a few more solutions and some new ideas/concepts.

Well, heuristic helped me to generate more ideas for my project.

Using the Size-Time-Cost [Operator] helped me generate realistic ideas even when thinking of money was not an issue. By thinking in such a wide point of view can create ideas that can then be broken down into more feasible goals.

Helped me to understand my problem better, so I was able to come up with more useful solutions.

It helped me to be more productive and think smartly.

We actually found more ideas than we had before.

MATCEMIB opens thoughts to other fields.

We used MATCEMIB and then IUR – We had more new ideas with the first one.

The following are student responses to the statement, ‘Learning the heuristics changed a way I resolve problems’.

It made me realise there is always a different way of solving a problem.

For the most part I already applied a lot of these subconsciously however I do approach the way I solve problems slightly differently.

Because it’s totally different to my thinking.

Heuristics give me a distinctive viewpoint towards a problem.

Taking time to analyse the problem and think of things that can be resolved with the given time or resources available, or what issues need to be solved in a different perspective.

Before I used the heuristics my way I solved a problem was always the same but the heuristics taught me there are so many different ways you can [take] solving a problem.

Using heuristics helped me to resolve my problems a lot easier than it used to be.

The following are student responses to the statement, ‘If you have success using the heuristics, please share with us your experiences’.
I was able to use heuristics throughout my project. When I was stuck, I was able to better define my problem, which helped me to come up with an innovative solution.

I have a problem with my project and the task was a little hard to do until I used heuristics and it helped me a lot to achieve the result that I wanted.

Well, I have already included the result, tasks and action into my report, so. That should be able to answer this question :)
Appendix D

TRIZ Repository: Comments from educators

Educators also reflected on a number of issues related to the use of TRIZ heuristics in engineering education. Below are some comments from academics that supplement their quantitative responses to the statement, ‘Educational materials offered by the TRIZ Repository are useful for my students’ presented in Table 5.

The educational materials provide examples and situations of various thinking processes to arrive at solutions to problems.

No doubt the more heuristics introduced to the students the better. The students are genuinely interested to learn about problem solving tools however time restrictions have limited my efforts to a shorter and easily to understand (in my opinion) heuristics.

It was really helpful to have the supporting tools available.

Current material is good, but as this process evolves the repository shall grow.

The following are academic responses to the statement, ‘Educational materials offered by the TRIZ Repository can be easily embedded in my subject’.

By first explaining the traditional engineering thinking process in arriving at a solution, students are encouraged to access EDISONS21 and examine different approaches especially in the situation of materials selection the STC.

Some examples are great especially for innovation. More examples are desirable for dealing with the existing engineering systems, e.g. how to make it, quicker, cheaper, more efficient, etc.

The problems in my subjects are ‘technically too clear’ to ‘sell’ the necessarily to the students to have them excited to learn TRIZ. I tried to teach the methods to my colleagues.

It’s simple enough to email links.

The following are academic responses to the statement, ‘I could use the educational materials offered by the TRIZ Repository with minimal adjustment (minimal time investment)’.

The material needs to be adapted to my particular style of teaching, and material content as well as problem definition and solution, and is not especially difficult.

One way or the other we have to adapt any materials to our courses and student profiles. I have not adjusted existing materials which have worked very well but can consider doing in the future and sharing with the Fellows.

I just modified the slides.

Good layout.
By way of conclusion, academics were asked to suggest improvements to the TRIZ Repository and the educational materials it offers. The following are some responses.

Offer additional case studies applicable to first-year students. Freshmen have pre-conceived ideas for problem solving, often learn or dictated to by what they were exposed to in a school environment. Often, first-year engineering is about problem solving and minimal project-based problem solving. It is during their first-year experiences that TRIZ would be a useful adjunct to problem solving especially in project-based environments.

Sharing educational materials among the providers through TRIZ Repository would be one of the improvements. And another one of cause more resources dedicated to the repository maintenance, for example I was very interested to introduce the method of smart little people but it was not available yet.

Make structure of cheat sheet and solution template coherent.

Formatting updates - instead of having hyperlinks use a ‘tree’ or ‘bread crumb’ style. This is only minor. As far as content – it is sufficient and should be updated as ongoing work takes place.
Appendix E

Reflection on learning and application of TRIZ heuristics

The application of TRIZ heuristics genuinely assisted me significantly in my engineering [capstone] project. Due to the broadness and uncertainty of this project title, having a template that allowed me to break down each small component and pinpoint my solution direction and consider details I would have not of thought of, opened up my creativity and allowed me to display information in different ways.

Although I didn’t use all heuristics, as they weren’t related to my problem, I will definitely use these skills learned in future projects. I feel the heuristics of IUR and MATCEMIB are fundamental heuristic materials that should be the foundation and starting point for all students/engineers who wish to solve a problem. Having a keen interest in sustainability and wishing to further my studies, I believe IUR and incorporating MATCEMIB or any other heuristic will definitely be beneficial to my future studies and real-life applications.

Suggestions to improve engineering curricula
Throughout my university studies I have had some instances of creative freedom while solving problems, although nothing came close to the amount of creative freedom I had with my engineering [capstone] project. In particular, the units of steel and concrete structures required my group and I to design a concrete high-rise building and steel warehouse. The financial aspect was not a factor and we took it upon ourselves to decide on the sizing of all elements, as long as it was sufficient enough. Besides this, there weren’t many other units that truly focused on creative thinking and allowing the students to explore their creativity through TRIZ heuristics and alternative thinking methods.

I would truly like to see a unit introduced in every engineering degree, especially 1st year that focuses on alternative thinking methods and an introduction to innovative TRIZ heuristics and how to apply these to all future projects. Just from myself being exposed to these heuristics and using the self-learning material, I gained an immense amount of knowledge and confidence in applying creative and alternative design methods and techniques when solving problems. If a whole unit were to be introduced and students were exposed to multiple problems throughout the unit/course and were taught how to apply each heuristic topic to different problems, many graduates would come out of university with a different mindset towards problem solving.
Appendix F

Publications directly related to Fellowship activities


Belski, I., & Belski, R. (2018). Are We Fit to Graduate Creative Professionals? In 2018 IEEE International Conference on Teaching, Assessment, and Learning for Engineering (TALE) (pp. 365-371). doi:10.1109/TALE.018.8615357.


Appendix G

References


Steiner, T., Belski, I., Harlim, J., Baglin, J., Ferguson, R., & Molyneaux, T. (2011). Do we succeed in developing problem-solving skills—the engineering students’ perspective. In Y. M. Al-Abdeli & E. Lindsay (Eds.), *The 22nd Annual Conference for the*
Australasian Association for Engineering Education (pp. 389–395). Fremantle: Engineers Australia.


# Appendix H

## Fellowship Impact Plan

<table>
<thead>
<tr>
<th>Table 7. Fellowship Impact Plan</th>
<th>Project completion</th>
<th>Six months post-completion</th>
<th>Twelve months post-completion</th>
<th>Twenty-four months post-completion</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Team members</strong></td>
<td>Recognition of expertise of FET by Australian community of engineering educators</td>
<td>Recognition of expertise of FET by engineering students worldwide</td>
<td>Recognition of expertise of FET by TRIZ community worldwide</td>
<td>Recognition of expertise of FET by community of engineering educators worldwide</td>
</tr>
<tr>
<td><strong>2. Immediate students</strong></td>
<td>TRIZ tools helped in developing novel project ideas</td>
<td>Some students are offered jobs because of the knowledge of TRIZ heuristics</td>
<td>Enhanced cognitive skills due to learning TRIZ tools and applying them regularly</td>
<td>Changes in engineering curriculum make graduates more employable</td>
</tr>
<tr>
<td><strong>3. Spreading the word</strong></td>
<td>Publications and presentations in Australia</td>
<td>Publications and presentations at students' gatherings in Australia and overseas</td>
<td>TRIZ materials used by students from at least 20 Australian universities and some universities worldwide</td>
<td>Journal publications and presentations on the outcomes of students' application of TRIZ tools</td>
</tr>
<tr>
<td><strong>4. Narrow opportunistic adoption</strong></td>
<td>Engineering academics from three to four Australian universities decide to embed TRIZ tools into their subjects</td>
<td>Engineering academics from eight to ten Australian universities try embedding TRIZ tools into their subjects</td>
<td>Engineering academics from at least 10 Australian universities embed TRIZ tools into their subjects</td>
<td>Engineering academics from at least 15 Australian universities embed TRIZ tools into their subjects</td>
</tr>
<tr>
<td><strong>5. Narrow systemic adoption</strong></td>
<td>Two or three Australian engineering schools decide to try teaching TRIZ tools explicitly</td>
<td>Four to five Australian engineering schools decide to try teaching TRIZ tools explicitly</td>
<td>At least two Australian engineering schools decide to incorporate TRIZ into curricula</td>
<td>Five or more Australian engineering schools incorporate TRIZ into curricula</td>
</tr>
<tr>
<td><strong>6. Broad opportunistic adoption</strong></td>
<td>Over 100 students use TRIZ in their project work</td>
<td>Over 500 students use TRIZ in their project work</td>
<td>Majority of coordinators of design subjects become interested in the repository of TRIZ materials</td>
<td>Majority of Australian engineering schools that participate in the EWB Challenge expect students to use TRIZ in their projects</td>
</tr>
<tr>
<td><strong>7. Broad systemic adoption</strong></td>
<td>Evidence of the effectiveness of TRIZ in students' project works is available and published</td>
<td>Engineers Australia consider suggesting engineering schools to incorporate teaching creativity skills</td>
<td>Australian engineering schools consider explicit teaching of creativity skills as a requirement</td>
<td></td>
</tr>
</tbody>
</table>

Educatiing the Edisons of the 21st Century