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TRIZ course enhances thinking and problem solving skills of engineering students

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Abstract

Forty two engineering students at RMIT were enrolled in a course on the Theory of Inventive Problem Solving (TRIZ), which was conducted over 13 weeks in semester 2, 2006. It was found that most of the students were unaware of any thinking and problem solving tools before the course. Results of the student surveys showed that students' perceptions of their abilities in problem solving changed vastly as a result of the course. Many students believed that their thinking had changed as a result. Students reflected that they would have never expected themselves to come up with the ideas they thought of and suggested while conducting their final project, if they had not been formally taught the tools of problem solving. It was also found that this course on TRIZ thinking tools impacted students' problem solving ability much more than the discipline-based courses.

Keywords: TRIZ; Thinking skills; Problem solving skills; Substance-field analysis; Method of the ideal result; Contradiction table; Seven steps to systematic thinking;

1. Introduction

Over the last twenty years, the engineering profession has been experiencing important changes. These changes have required engineers to become more efficient in thinking and problem solving. More specifically, they demand engineers to resolve problems quickly, to consider open-ended problems, as well as to cope well under uncertainty and information overload.

The natural life of products shortens every year. Some of the new products make the existing products, which are often only a couple of years old, obsolete. This trend of shortening life span of products is putting significant pressure on R&D teams to reduce the product development time. Many engineering managers think that an average time given on project development has been cut by nearly three times since the 1980s. Then, teams were given 36 months to be delivered what is now expected within 12 to 15 months. Indeed, the advances in science and technology and availability of various computer-based simulation tools have helped in achieving this. Nonetheless, shortened development time puts a significant pressure on engineers and scientists to deliver novel solutions quickly and requires them to resolve engineering problems with extreme efficiency.

Furthermore, engineers of the 21st Century are facing very different challenges to what they were just 20 years ago – more and more problems they encounter are open-ended. In the words of Charles Handy, "Life seems to be a

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succession of open-ended problems with no right answers, but problems, nevertheless, which demand an answer" [1]. In other words, engineers now have to resolve problems they have never experienced before, delivering solutions which have often been unheard of.

Moreover, the amount of technical information doubles every two to three year [2], making it practically impossible for engineers to be aware of all the recent advances in technology. Thus, engineering decisions need to be made under conditions of uncertainty and significant information overload.

Former US Secretary of Education Richard Riley recently stated, that "…the top 10 jobs that will be in demand in 2010 didn't exist in 2004…We are preparing students for jobs that don't yet exist…" [2].

All these factors: the need to be able to resolve problems quickly and with minimised failures, the ability to consider open-ended problems, as well as the capacity to cope well under the information overload and uncertainty, put an engineer under unfamiliar pressure. Engineers are required to think more efficiently and to resolve the problems that they face better. To achieve this, they need to be properly trained in efficient thinking and problem solving tools. Such training can be conducted both during university study and as workshops for skills upgrade while at work. Moreover at university, problem solving tools can be taught as a separate course as well as embedded into discipline-related courses.

Various publications have indicated the efficiency of teaching engineers and engineering students the thinking tools of TRIZ [3 – 7]. Practicing engineers, for example, have used tools of the Theory of Inventive Problem Solving (TRIZ) in their day to day work and have been able to achieve significant improvements in the outcomes of their work. The following are some of their opinions [6]:

"On the whole, TRIZ tools offer a systematic thinking process which effectively reduces the traditional thinking process like brain storming, fish bone diagram, etc. It assists the designer by recording the thinking process, which eventually leads to the solution. In this way, the points discussed during the thinking process will not repeat themselves."

"TRIZ brought out the structure of ideas and thought in various stages to solve my project. Although the solution was pretty much similar to the current solution, the time required in deriving the solution was shorter (i.e. 2 months instead of 12 months). The cost of trial and error was eliminated therefore reducing the developmental cost. Should this project have started with TRIZ, cost, man-hours and development lead-time could have been significantly reduced."

"Through the application of the various TRIZ tools, it has helped in generating various possible solutions which were previously not thought of."

These reflections, as well as opinions of many engineers involved in TRIZ4U training programs and the tangible outcomes of the training [6] support the effectiveness of learning thinking and problem solving tools at work. Nonetheless, most of the engineers involved in TRIZ4U training agreed that formal university courses designed to boost thinking and problem solving skills of future engineers would be much more efficient and timely. The following is a reflection of an engineer from Singapore, who was involved in learning TRIZ thinking tools for six months, which summarises the need for teaching thinking at schools and universities [3].

"After spending six months trying to understand and adopt the TRIZ problem solving methodology, I personally feel that it is an innovative thinking process which effectively reduces the traditional thinking process. Through our educational system, we have been taught/brainwashed on how to solve problems with the correct solution. We are always eager to look for the correct answer, and most often neglecting the minor details which are critically related to the problem. With the help of TRIZ, I began to understand the importance of looking at a task from a wider perspective, writing down the thinking process and generating a more disciplined and systematic approach when it comes to problem solving, and this is especially beneficial when it involves a complex system."

The author has been teaching the basics of TRIZ thinking at the Royal Melbourne Institute of Technology (RMIT) since 1997, but only in 2006 has he been able to introduce the course fully devoted to the tools of TRIZ as a university-wide elective. As expected, the course outcomes demonstrate its extreme efficiency in boosting the thinking and problem solving skills of engineering students.

2. Method

Forty two engineering students, in their second to fourth year of study, were enrolled in a RMIT-wide elective course “Systematic and Inventive Problem-solving” in the second semester of 2006 (July to November). During the 13 weeks of semester, they studied the following four thinking tools of TRIZ: Situation Analysis, Method of the Ideal Result, Contemporary Substance-Field Analysis, 40 Innovative Principles with the Contradiction Table. Every student had to complete four individual assignments, which were related to specific thinking tools and participate in group project work over a three week period. The projects undertaken by the student groups were related to various needs of the Australian community. The following are some of the project titles: “Improving safety of traffic lights”, “Getting rid of cane toads”, “Detection of rip currents”.

The project had to be undertaken using the Seven Steps of Systematic Thinking [8].

2.1. Thinking tools of TRIZ

TRIZ is the Russian acronym for Theory of Inventive Problem Solving. It is a well-established system of tools for problem solving, idea generation, failure analysis and prevention. TRIZ originated in Russia more than 50 years ago [12]. TRIZ thinking tools branch from the evolution of products and processes, which have been revealed through the analysis of thousands of patents. Developed behind the iron curtain, TRIZ was used by Russian engineers and contributed to many inventions. TRIZ entered the Western world in the early 1990s, and has already helped many western companies in achieving enormous improvements.

The following is a short description of the tools which the students were taught.

2.2. Situation Analysis (SA)

Situation Analysis was used by students as the first thinking step, on the way to situation improvement. SA is designed to question the assumptions of a user and his/her perception of the problem. To solve a problem, it is imperative to understand what the problem is about. Our perception of the situation and our entire outlook concerning its improvement often changes when various needs of the situation become apparent.

When humans consider real problems (situations) they often mix many issues together. Technical matters are often blended together with human emotions. These issues are indeed related, but they often correspond to very different aspects of the situation and can therefore be dealt with differently. Usually, the people improving the situation attempt to address all the human and technical issues at once. This is not the most efficient method by which to achieve success. Proposed actions rarely achieve the outcomes expected. An approach such as this often results in time and resources being wasted.

The SA tool deployed in this study required students to answer a set of 11 questions [9]. This was intended to achieve the following outcomes:

- to clarify the situation under consideration
- to separate human perceptions from the reality of the situation
- to identify different problems embedded in the situation
- to formulate the tasks that were to be undertaken for the situation improvement

2.3. Method of the Ideal Result (MIR)

Method of the Ideal Result (MIR) has been developed by the author [10]. MIR is based on the TRIZ notion of the Ideal Ultimate Result (IUR). It has been found that when engineers face problematic situations and need to devise some improvements, two main issues are especially challenging. They are [9,10]:

- to identify the most problematic issue to focus on during the improvement
- to be able to utilise the resources which are available, almost for free.

We often find ourselves in situations where improvement is necessary, but the element that should be focussed upon is not always apparent. Identifying the correct element to focus on is vital. Unless an engineer applies his/her skill and invests money into upgrading the system part which holds up overall performance the most, the outcome of such improvements is likely to be quite unsatisfactory. The first part of MIR is designed to aid users in pinpointing the very element upon which to focus.

Another common mistake made by many engineers is related to the introduction of additional resources (e.g. new parts, elements, substances, etc.) to improve the situation, without having a clear picture of what resources are originally available. Any new resource costs money. Most existing resources are either free or inexpensive. Moreover, the existing resources are already available and do not need to be supplied! The second part of the MIR procedure helps a user to identify the resources available, and consider how these resources may be used in improving the situation.

Overall, MIR helps a user to accomplish the following:

- to identify the direction towards an effective and simple solution
- to separate different areas of improvement, and to identify the elements one needs to focus on to deliver the most efficient improvement
- to recognise all the resources at hand
- to sift through all the available resources, with the aim of seeing whether they may help in improvement

All students in the trial used MIR by employing the *TRIZ4U MIR Proforma* [9].

2.4. Contemporary Substance – Field (Su-Field) Analysis

Substance-Field Analysis represents any natural and man-made system as a set of interacting elements – a set of *substances* interacting with each other by means of *fields*, which are generated by the substances. Substances and fields in Substance-Field Analysis are not equal in representing systems – substances describe real system elements and fields show the interactions between these elements. Nonetheless, both substances and fields are represented in a similar manner – by circles. This ensures that vastly different real systems are modelled in a similar way – by means of *circle-substances* and *circle-fields*. Such generalisations enable a practitioner to represent complex systems by simple structures of circles. This allows a user to consider different systems in a uniform way and to apply similar rules to resolve dissimilar problems. An example of a two-dimensional representation of a system, as a set of fields and substances, is shown in Figure 1. The circles with the letter S represent substances, the circles assigned with F symbolise the fields generated by these substances.

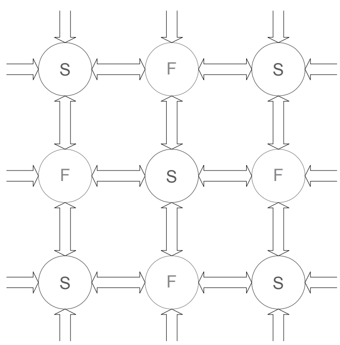

Figure 1. A two-dimensional representation of a system in Su-Field

The real picture of a system is often more complicated and has more dimensions than the one shown. Nonetheless, such models and generalisations of circle-substances and circle-fields help to systematise our thinking.

Su-Field Analysis is a general tool for idea generation and failure analysis and prevention. It models a system through a set of interconnecting substances and fields. This converts the real task into its Su-Field model and helps to clearly identify the *conflict zones* of the system. These conflict zones are broken down into *conflict triads.* Five model solutions are considered for every conflict triad. Eight fields of MATCEMIB (Mechanical, Acoustic, Thermal, Chemical, Electric, Magnetic, Intermolecular, Biological) are then deployed to "translate" model solutions into real solutions.

Students were taught the procedure of the contemporary Su-Field Analysis, consisting of 5 model solutions [9, 11], which replace the classical 76 Standard Solutions [14].

Most students also used contemporary Su-Field Analysis [11] for both idea generation and failure prevention.

2.5. The Contradiction Table (CT) and 40 innovative principles

The 40 Innovative Principles are "solution recipes" that have been successfully used in thousands of patents. To derive the 40 Innovative Principles, more than 20,000 patents were analysed [12]. It was found that dissimilar tasks from distinct areas of engineering and science were often solved in a similar manner. The 40 Innovative Principles combine these ideas into larger groups, called principles. The 40 Principles can be used separately, but they yield better solutions when used together with the Contradiction Table. The Russian versions of the TRIZ Contradiction Table (CT) and 40 Innovative Principles have remained unmodified for over 25 years.

The Contradiction Table (CT) and 40 Innovative Principles, when used together, represent another idea generation tool which models real systems. Unlike Su-Field, which provides the user with a wide variety of general ideas for implementation, these tools offer solution ideas which are design-ready. The *TRIZ4U CT Proforma* was utilised by the students to model systems accurately [9].

2.6. Seven steps of systematic thinking

All students were asked to conduct their practical work using the Seven Steps of Systematic Thinking [5]:

1. Situation analysis.
2. Revealing the system's stage of development.
3. Identifying the ideal solution.
4. Idea generation.
5. Failure prevention.
6. Adjusting the super-system and sub-systems in accordance with the solution found.
7. Reflection on the solution and the process of the solution.

Student project teams were required to submit the formal project reports. Reflection on the solution, the process of the solution, problems encountered during the solution process, changes in thinking pattern, etc. was a compulsory part of the report.

3. Results

The results presented here come from three different sources:

- RMIT Course Experience Survey (CES), independently conducted by the university during classes in week 10 of the semester and completed by 34 students,
- Pre- and post-course surveys conducted by the author in week 1 and in week 13 of the course and completed by 30 and 32 students respectively,
- Student reflections on their achievement and experience (step 7 of the formal Project Report, completed by 42 students).

3.1. RMIT CES Results

Students evaluated the course very highly. All but one of them were either strongly satisfied (25) or satisfied (8) with the quality of the course. One student was unsure. Similar opinions were expressed on the usefulness of the course for their future career (22 – strongly agreed, 11 – agreed, 1– unsure). Exactly the same was the distribution of the student answers to the question "This course contributes to my confidence in tackling unfamiliar problems" (22 – strongly agreed, 11 – agreed, 1– unsure).

The following are some students' opinions:

"Course is very interesting and relevant to engineering. It should really be a core subject..."

"It just makes you look at things from a wider angle and from all angles. Therefore it exercises your brain to think of things you do not think of."

"The course is extremely useful in enabling a person to deal with unfamiliar problems with a systematic approach."

"... able to learn how to think and come up with a solution that seems far fetched yet possible."

3.2. Pre- and post-course surveys results and student reflections

The following are student opinions of their ability to resolve problems, collected in week 1 (Figure 2) and in week 13 (Figure 3) of the course [13].

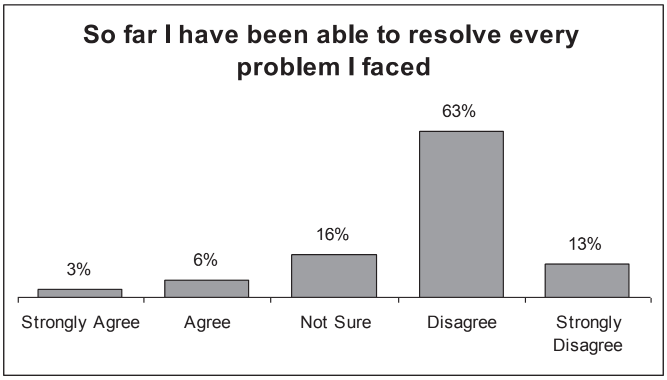

Figure 2. Student opinions on their ability to resolve problems that they face, week 1

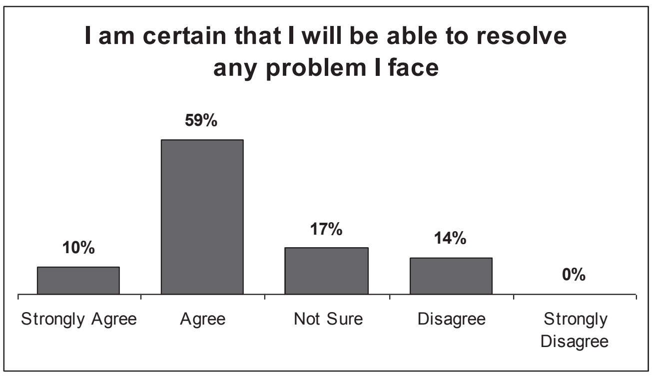

Figure 3. Student opinions on their ability to resolve problems that they face, week 13

The data in Figures 2 and 3 shows that the number of students who were certain of their good thinking and problem solving abilities increased nearly eightfold – from 9% to 69% as a result of the course. Also, in week 1, 76% of students thought that they were unable to resolve every problem. This number went down more than 5 times – to 14% in week 13, after the course had been completed.

It is also of interest to consider self-evaluation of the students' problem solving skills, presented in Figure 4, which represents their responses to the statement: *"I am very good at problem solving"*.

The shift from the average response of "Not Sure" to the average opinion of "Agree" is clearly visible and is statistically significant.

Student opinions depicted in Figures 2 to 4 are very encouraging. They clearly show that the students' perception of their thinking and problem solving skills have improved significantly as a result of studying the tools of TRIZ and applying these tools to assignments and the project. It is, however, unclear how reliably student opinions identify real improvement of their thinking and problem solving skills.

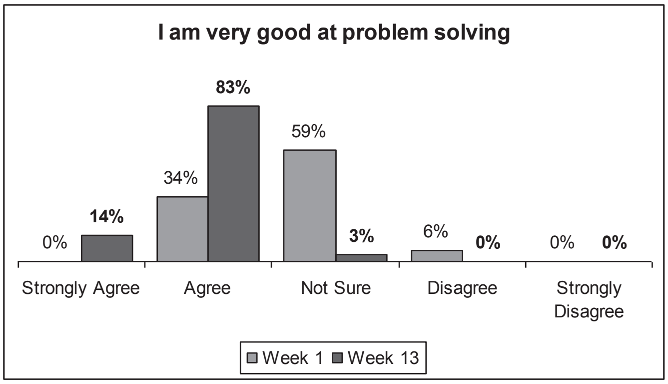

Figure 4. Change in the students' self-assessment in problem solving as a result of the course

Nonetheless, as the 14th Century proverb states "there is no smoke without a fire". Students enrolled in the TRIZ thinking course have learnt a number of efficient tools for systematic thinking and problem solving and were able to use these tools to generate many good solution ideas. This, for certain, helped them to enhance their thinking and problem solving skills.

The following are the reflections of students, which further support the findings [13]. Reflections are grouped to highlight the changes in thinking and problem solving of students related to the three main challenges in educating engineers, as identified earlier.

3.3. Improved ability to tackle open-ended problems

The following are quotations related to the students' ability to deal with open-ended problems. They come from the student questionnaire answers as well as from their project reflections:

"I feel more confident to undertake unfamiliar problems knowing there is a systematic approach to solving the problem."

"(I have developed) ability to approach unfamiliar tasks and overcome them."

"I am able to see problem as a challenge, not an intimidation."

"I have developed more confidence in approaching unfamiliar problems."

"I have been able to learn new tools and become more confident with tackling both technical and non-technical problems."

"Have the confidence to tackle new problems effectively."

"(I have developed) clear thinking, ability to tackle unfamiliar problems."

"(I have developed) an ability to tackle any problem."

"I learnt how to tackle problems I never thought that would have been faced or solved by me."

"After completing this task and the TRIZ course I believe that I am in a much better position to tackle problems in the future, both engineering related and anything else that comes my way."

3.4. Improved structured and systematic thinking

The following student opinions relate to enhancement of their systematic thinking:

"(I) know what to do and how to solve problems. Not just rushing to solve the problem based on experience and knowledge only."

"(I) can think of unique solutions to problems."

"(I gained) better systematic and analytical thinking."

"(My thinking) follows a far better structure; instead of hitting my head on the desk, hoping for a solution, I have a method to make me realise a viable solution(s)."

"(the course) helped me to follow a systematic way in order to solve problems."

"I feel I am approaching problems in a more logical manner."

"I normally attack problems to the core, now. I can at least use the tools of TRIZ to attack problems in a different manner and may end up saving a lot of time effort and understand more about the problem."

"My thinking mindset has become more structured."

3.5. Looking beyond the current knowledge

The following student opinions relate to the changes in their thinking, which help them to look beyond current knowledge.

"(My thinking) did change, as in, it made me think of all possibilities rather that only technical results."

"(The course) just makes you look at things from wider angle and from all angles. Therefore it exercises your brain to think of things you do not think of."

"Using the TRIZ tools has forced my mind to think of a problem from different perspectives in order to come up with good solution to the problem."

"... my thinking ... broadened to look at previously ignored possible solutions."

"My thinking changed. It helped me generate a wider range of ideas and to identify the problems."

"(The course) helped me to think outside the square that I usually think in."

3.6. "Has your thinking changed"?

The following are student answers to the questions "Do you think that your thinking changed as a result of this course? How did it change?"

"Yes it changed my thinking because now I look at things from different angles. Therefore, having a wider view."

"My thinking in regard to the every day problem has changed. I intend to analysing the problem using the TRIZ tool, instructed in this course. Solving problems for me personally became more fun."

"I personally think it will take quite a bit of time for my thinking to change 100%, however this course has definitely provided a new way of thinking that will be developed over a period of time."

"Yes, it allowed me the tools to help myself in everyday as well as technical life."

"Yes. I can think more effectively."

"Yes. I break problems into smaller tasks now."

"Yes, the ability to look at problems from a different perspective. Not always looking for the technical solution."

"Yes, my thinking mindset has become more structured."

"Yes, it did. Ideas are more formed neatly and ways to come up with the solution is more systematic."

3.7. Good problem solving skills

It is also interesting to evaluate the students' judgement on what 'good problem solving skills' mean to them. Figure 5 compares students' answerers to the following two questions, which were asked in week 1, before students started learning the tools of TRIZ:

- *I am very good at problem solving*
- *So far I have been able to resolve every problem I faced*

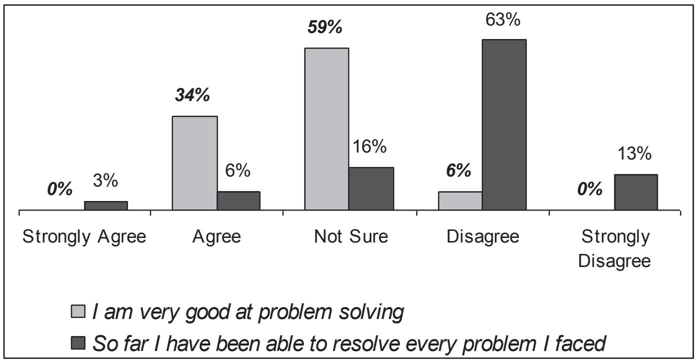

Figure 5. Student opinions on being good at problem solving before the course

Figure 5 reveals, that students' opinions of the skills of a very good problem solver do not presume an ability of resolving every problem faced. Only 9% of students stated that they have been able to resolve every problem in the past. At the same time 34% of them evaluated themselves as very good problem solvers. Also, only 6% of students thought that they are certainly not very good in problem solving, while 76% of them were unable to resolve every problem they have faced.

Figure 6 compares students' answers to two similar questions, which were asked in week 13 of the course:

- *I am very good at problem solving*
- *I am certain that I am able to resolve every problem I face*

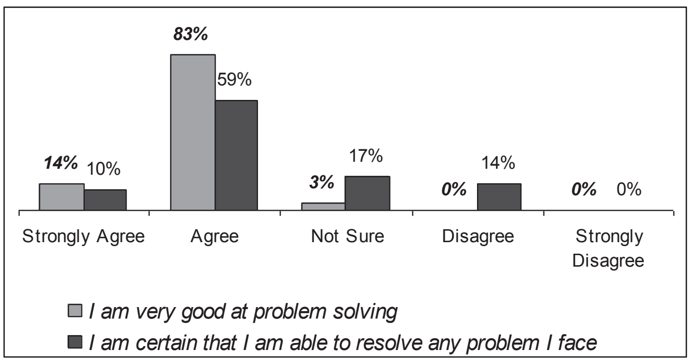

Figure 6. Student opinions on their success in solving problems after the course

Students' judgements of their abilities to resolve every problem in the future after the course vastly differ to their opinions on their abilities before the course. Almost 31% of students do not expect to be able to resolve every problem that they will face in the future; nonetheless, only 3% of respondents evaluated their problem solving abilities as less than very good.

The data presented in Figures 5 and 6 clearly confirm that opinions on our abilities to do something are based on our perception, rather than on some measurable outcome. Although student opinion on problem solving ability after the course, presented in Figure 6, is well correlated with their perception of their real skills, opinions of the same cohort before the course, pictured in Figure 5, show little correlation.

This indicates that the *opinion* of an ordinary engineering student on being very good in problem solving is not equivalent to being *able* to resolve any problem he/she faces.

3.8. Teaching problem solving skills as a separate course

Many discipline-related university courses identify improved problem solving abilities of the students as a by-product of a discipline-related course. Many academics believe that while involved in resolving problems related to a specific discipline (e.g. Electronics, Mechanical Engineering, Chemical Engineering) students are able to enhance their thinking and problem solving skills sufficiently well. Moreover, they often trust that formal courses on thinking and problem solving would not enhance student problem solving skills any better.

Discussion on the effectiveness and impact of teaching thinking and problem solving as a separate course, versus integrating it into discipline-related content, is still open but tends to favour separate thinking courses as more fruitful [15]. To compare the impact of discipline-based versus specifically designed courses on thinking skills on students' problem solving ability, the data from RMIT CES on all the discipline courses of the School of Electrical and Computer Engineering (BP200) and the TRIZ thinking course (OENG1045) were evaluated. Figure 7 presents the distribution of student answers to the statement: "*This course contributes to my confidence in tackling unfamiliar problems"* for both BP200 (656 students) and OENG1045.

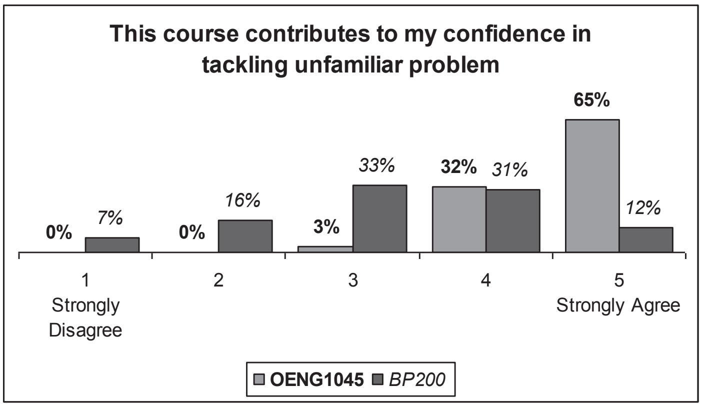

Figure 7. Comparison of student opinions on the impact of the TRIZ thinking course (OENG1045) and discipline-related courses (BP200) on their problem solving ability

The results presented in Figure 7 reveal a significant difference between the impact of the TRIZ thinking course compared to the discipline-based courses on student problem solving skills.

4. Summary

Student surveys conducted in week 1 identified that most of the students were unaware of the existence of any formal tools of thinking and problem solving. Also, many of them were uncertain that their choice of the course was wise. At the end of the course it even became clear that some of the students enrolled into the course 'by luck':

"I was always interested in this subject but in the end only chose it because the electronics subject I had chosen clashed with another. That was a great thing to happen as I see these methods of thinking as life changing, not just another bit of theory that may or may not be used at some stage in the future."

The outcomes of the course on thinking and problem solving and the data presented here clearly support the opinion of engineers [6] and of existing research in cognition [15], that emphasise the importance of involving engineering students in specialised courses on thinking and problem solving. The current findings demonstrate the superiority of specialised courses to discipline-related courses, which embed thinking tools, but do not teach them explicitly.

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