Measuring the style of innovative thinking amongst engineering students

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Structured Abstract

Background

Many tools were developed to measure the ability of workers to innovate. However, all of them are based on self-reporting questionnaires, which raises questions on their validity.

Purpose

Our aim was to develop and validate a tool with which one could objectively measure the style and potential of engineering students in generating innovative technological ideas. Its cognitive framework is based on the Architectural Innovation Model (AIM).

Tool description

We designed it to measure the level of innovation in generating technological ideas and their potential to be implemented. These variables rely upon the assumption that defines innovation as "creativity, implemented in a high degree of success." The levels of innovative thinking are based on the AIM and consist of four levels: *incremental* innovation, *modular* innovation, *architectural* innovation and *radical* innovation.

Sample

Sixty experts in tech-innovation developed the tool. We checked its face-validaty and calculated its reliability through a pilot study (Kappa=0.73). Following, a group of 145 undergraduate students were sampled randomly from the seven Israeli universities offering different engineering programs and asked to take the questionnaire.

Design and method

We examined the *construct validity* of the tool by conducting a variance analysis and measuring the correlations between the innovator's styles of each student, as suggested by the AIM and the three subscale factors of the creative styles (*efficient*, *conformist* and *original*) as suggested by the KAI questionnaire (Kirton, 1976).

Results

We found that students with a radical innovator's style inclined more than students with incremental innovator's style towards the three creative cognitive styles. However, the students with the architectural innovator's style inclined only moderately towards the three creative styles, but not significantly.

Conclusion

The tool objectively measures innovative thinking amongst students, thus allowing screening of potential employees in as early a stage, as at the stage of their undergraduate studies.

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Abstract

This paper describes a tool titled Ideas Generation Implementation (IGI) that we have developed in order to measure the style/type and potential of engineering students in generating innovative technological ideas. The cognitive framework of the tool is based on the Architectural Innovation Model (AIM). It was found to be reliable and valid in measuring the style and potential of technological innovation of engineering students.

Key words: Innovation, engineering students, technology, potential.

Introduction

In the eighties, technological innovation was defined (Porter, 1990) as a technological improvement or as a method of doing things better. Nowadays, researchers stress that innovation is not revolutionary in its essence. To some (Schwartz & Malach-Pines, 2007) it just constitutes minor changes, rather than significant breakthroughs; it involves a set of ideas that, on the one hand, are not new, rather just not in use en-mass as yet, and on the other hand, it needs some entrepreneurship to apply the changes in new ways and settings.

To others (Harmancioglu et al., 2009) technological innovation is present in the realm between a newly developed product wrapped in its marketing strategy, and between the development of a new product that changes the manner in which people think about it.

According to a report by the OECD (PIACC, 2010), employees' problem solving skills have great value in the context of organizational and corporate survival in the ever increasing global competition for innovation. Nowadays, it is well accepted to say that in contemporary knowledge based societies, the extent of economic success and survival is dependent upon employees' innovative state of mind and culture (Kim & Maubourgne, 2005). Effective employees are able, simultaneously, to assess the requirements of the market, define and develop innovative products, which could be commercialized and provide the company with a leading edge in global markets (Makri & Scandura, 2010).

As one can see in table 1, many tools were developed in the course of the last half a century with the aim of better measuring the ability of a vast array of workers to innovate. However, all of them are based on self-reporting questionnaires, which raises a whole series of questions regarding their validity. Baron (2006), for instance, argued that these tools are not based on cognitive foundations, and that research on cognitive aspects of entrepreneurship and innovation could lead to better tools.

Table 1. Summary of properties of tools, measuring Innovative Thinking

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According to Baron, it is important that tools would address three main questions: why do some people, but not others, turn to be innovative? Why some people, but not others are capable of identifying opportunities in innovative products or processes, which are both effective and commercially viable? And why some innovative entrepreneurs are more successful than others?

However, the appeal to undertake such venue of studies, generated mainly self-reporting questionnaires and thus the cognitive aspects that were analyzed turned to be very limited (Krause, 2004; West et al., 2003).

Moreover, the Industry Skills Innovation & Business Report (IBSA, 2006) pointed lately to the significant importance of not just measuring innovative skills of workers but also of training students in mastering innovative skills and strategies, which they will require in the future, as professional workers in their industries.

In that regard, even after engaging in a through literature review we could not identify a tool that aimed at measuring the innovative skills of students in order for the individual or the teacher to assess the needs and engage in training the lacking innovative skills. We also could not find a tool that aimed to measure objectively the quality of the changes proposed in the innovative process. Thus, we engaged to develop a tool we name Ideas Generation Implementation (IGI) to better address, on the one hand, the appeal of various studies to implement cognitive elements in training for technological innovation and on the other hand to better reflect objectively the ability of students to innovate (Zhao & Seibert, 2006).

In order to complement what is missing in the existing tools, we have tested in this study the Architectural Innovation Model (AIM) (Henderson & Clark, 1990) (Figure 1) as a cognitive framework for measuring levels of innovation in the development of new technological ideas amongst engineering students. The tool includes a pointer for measuring ideas, examined on their merits, and the potential of their implementation. To the best of our knowledge these measurements have yet to be undertaken by existing tools.

Figure 1. The Architectural Innovation Model – AIM (Henderson & Clark, 1990)

Variables

In this study, we have used two dependent variables: the level of innovation in the development of technological ideas and the potential for their implementation. Those variables rely upon the assumption that defines innovation as "creativity, implemented in a high degree of success," as some have suggested (Janssen, 2001; West, 2002).

Innovative level

The level of innovation in the technological ideas was rated by a group of experts from the hi-tech industry using a questionnaire. The questionnaire, which was based on the Architectural Innovation Model (AIM) (Henderson & Clark, 1990), aims at measuring four levels of innovative thinking: *incremental* innovation, *modular* innovation, *architectural* innovation and *radical* innovation. The levels of innovative thinking reflected two dimensions in innovation. First, the components dimension, i.e., the extent of change in the *components* of the proposed technological idea compared with existing components; and second, the architectural dimension, i.e., the extent of the change in *integration* between the components of the proposed technological idea, compared with the integration between components of an existing technology.

Innovative type

According to the AIM, there are also four types of innovative thinkers in developing technological ideas:

1. the *radical* type, whose ideas are based on a *drastic change* in the components of an existing technology and a *drastic change* in its architecture;
2. the *architectural* type, whose ideas are based on a *moderate change* in the components of an existing technology and a *drastic change* in its architecture;
3. the *modular* type, whose ideas are based on a *drastic change* in the components of an existing technology and a *moderate change* in its architecture; and

4. the *incremental* type, whose ideas are based on a *moderate change* in the components of an existing technology and a *moderate change* in its architecture.

The potential of implementing the innovative technological ideas was measured with the help of a group of experts working in innovation in a variety of hi-tech industries, using the following questionnaire that was completed by a group of engineering students.

Methodology

The methodology in this study had two tiers. The first tier aimed at developing the research tool and validating it. The second tier aimed at applying the tool in a random sample of subjects and determining the level and style of their innovation skills. Thus, the participants in this study consisted of two groups of audiences. The first group consisted of 60 engineers, working in departments of innovation in a variety of hi–tech industries in Israel. This group assisted in developing, judging and validating the IGI tool. The second group, described below, consisted of 145 students and served as the research group.

First tier: developing and face validating the tool

A group of 60 experts

In order to gather the first group of experts, with which we developed the tool and validated its face, we have sent inquiries to a list of 100 leading high-tech companies that are known to have prestigious departments of innovation and asked the head of the departments to voluntarily take part in this study. 60 of them, all males, aged 26-50 that hold a graduate degree in engineering, have responded positively to our request and formed the group of experts in this study.

Questionnaire

We then conducted a literature review in order to develop a list of technologies that need innovation in the coming decades. The review was based on major venues describing potential future technologies such as the "The Futurist" (published by the World Future Society www.wfs.org), the "Technology Review" (published by MIT www.technologyreview.com) and other publications by technological forecasting centers around the world such as NIC (2004, 2008) and the TechCast virtual forecasting think tank www.techcast.org (Halal, 2010).

We were able to gather a list of 20 technological fields that emerged as the major problems in need of innovation in the future. We then asked the group of 60 experts to rank those problems in a scale of 1 to 10 (Table 2), reflecting the necessity for technological innovation and the feasibility to implement the innovation based on the current state of scientific paradigm.

Table 2. Averages and standard deviations of the most important technological fields in need of innovation.

The results as seen in table 2 are the following six technological fields that the group of experts considered to be the most important ill-defined classes of problems facing humanity in the following decades and in need of innovation (M> 8 ; high scores > 75%):

1. Preventing road traffic accidents;
2. Alternative energy sources;
3. Solving water pollution problems;
4. Improving the functionality of the physically impaired;
5. Increasing the efficiency of disease diagnosis; and
6. Solving air pollution problems.

Based on this rating we have developed a questionnaire on which we report herein and which we title: Ideas Generation Implementation (IGI).

The IGI Tool

The purpose of the IGI tool is to identify the different styles of innovators and measure the potential of implementing ideas generated by these styles in the above six technological fields (Figure 2). It aimed to examine how students generate innovative solutions to global challenges that are considered to be ill-defined problems. According to the literature (Newell & Simon, 1972), this type of problems does not have a clear route of resolution and a skillful search of various databases, containing many alternative solutions, usually promotes innovative resolution.

Figure 2. A sample page from the IGI questionnaire.

The tool asked the participating students in this study, as described in the following second tier part, to generate future images of technologies, which may facilitate the resolution of the problems in need of innovation. The solutions proposed by the students were measured by another group of three senior experts. All three hold a Graduate degree in engineering and spent many years specializing in the development of technological innovations in various high-tech industries.

These senior experts were asked to evaluate the solutions proposed by the students using pre-defined criteria. These criteria were borrowed from similar tools, such as the evolutionary model of technological change (Anderson & Tushman, 1990), the two-dimensional taxonomy of products and innovations (Shenhar & Dvir, 1996) and the Architectural Innovation Model (Henderson & Clark, 1990) that measure levels of innovation in technologies.

Face validation with the group of 3 experts

These senior experts were asked to estimate the face of the tool and its validity to measure technological innovative thinking. They confirmed that the face is clear to examine the capability of innovative thinking in both aspects: measuring the level of innovation and measuring the potential for the implementation of the idea.

The three experts were asked to rate the degree of change in the *components* and *architecture* of the ideas proposed by the students, compared with the components and architecture of an existing technology aimed at solving a similar problem or even the same problem.

They were asked to grade the idea on a scale of 1-5 based on the following criteria:

1. There is *no change* in the *components* and *no change* in the *architecture* of a similar technology.
2. There is a *moderate change* in the *components* and a *moderate change* in the *architecture* of a similar technology (incremental innovation).
3. There is a *drastic change* in the *components* and a *moderate change* in the *architecture* of a similar technology (modular innovation).
4. There is a *drastic change* in the *architecture* and a *moderate change* in the *components* of a similar technology (architectural innovation).
5. There is a *drastic change* in the *components* and a *drastic change* in the *architecture* of a similar technology (radical innovation).

The final score of each student included the sum of scores received from all the ideas he has generated. The three experts were also asked to judge the extent to how each idea could be implemented, based on current scientific paradigms, in a scale of 1-5:

1. The proposed idea *is not* an implementable innovation based on current science
2. The idea has *low potential* of being implemented
3. The idea has *medium potential* of being implemented
4. The idea has *high potential* of being implemented
5. The idea has *very high potential* of being implemented

Reliability with a pilot study

In addition, the tool was distributed to a preliminary sample of ten students from different universities and examined as a pilot study. The ten questionnaires we administered generated a total of 60 innovative technological ideas. The ideas, generated by the students, were judged by the group of three experts. To that end, we have examined the correlation between the experts' grading with respect to the technological components of the ideas, their architecture and the potential for their implementation.

The reliability among the three judges was calculated with the Kappa test. We found that for the change in the *components'* dimension the percentage of pertinence among the experts was 83% (Kappa = 0.73, p <0.001), for the change in the *architecture's* dimension the percentage of pertinence was 82% (Kappa = 0.73, p <0.001) and for the change in the *potential for implementation's* dimension the percentage of pertinence was 78% (Kappa = 0.64, p <0.001).

Also, based on the students' answers in the pilot study, we have developed two indices, and calculated the level of their reliability, as a research tools.

1. The *level of innovation* in the development of technological ideas:

   This index was built out of an average of 12 items (evaluation of the change in the *components* and *architecture*'s dimensions of six technological problems). The scores ranged from 1 to 5. The higher the grade was, the higher was the level of innovation. The average was *M*=3.15, and the standard deviation was *SD* = 0.61. The reliability was α = 0.82.

2. The *potential for implementation* of the technological ideas:

   This index was built out of an average of six innovation ideas that had their potential for implementation *high* or *very high*. The scores ranged from 1 to 5. The higher the grade was, so was the potential for implementation. The average was *M*=2.95, and the standard deviation was *SD*=0.60. The reliability, after Spearman-Brown correction, which was applied due to the scantiness of items included in this index was α = 0.75.

Second tier: employing and construct validating the tool

A group of 145 students

The second group of subjects in this study, on which we employed the tool and with which we validated its construct, consisted of 145 students, who were sampled randomly from a pool of undergraduate students in their second year or above of studies in engineering programs in the seven Israeli universities offering different kinds of engineering programs.

In order to gather this group, we posted adds in campuses and in internet forums used by students in engineering, asking for volunteers. We have received 542 applications from which we have randomly sampled with SPSS 150 applicants and send them a link online to fill in the questionnaire anonymously. They were asked to complete the questionnaire in two weeks after which the access to the questionnaire was revoked. 145 students completed the assignment in two weeks and formed the research group of students (n=145) in our study.

The 145 students studied engineering in a variety of fields, such as software engineering, electrical engineering, computer engineering, mechanical engineering, bio-engineering, civil engineering, industrial engineering, communication systems engineering, and material engineering. Students in these programs may well be the next generation of Israeli hi-tech employees. We believed that the results of this study if implemented could have implications on syllabuses, curricula and teaching methods aimed at training students to serve as innovation agents of the future.

The 145 students were asked to propose ideas that could solve each of the problems they were presented with through the questionnaire (Figure 2). First, they were asked to address the change in the *components* of their proposed technology, compared with those in an existing or similar technology. Thereafter, they were asked to address the change in the *architecture* of the technology they proposed, compared with the architecture of an existing or similar technology.

Construct Validity

In order to examine the *construct validity* of the IGI tool, we conducted a variance analysis and measured the correlations between the innovator's styles of each student, as suggested by Henderson & Clark (1990) in their Architectural Innovation Model (AIM) and the three subscale factors of the creative styles (*efficient*, *conformist* and *original*) as suggested by Kirton (1976) in his KAI questionnaire.

We found statistically significant differences between the innovator's styles in the three creative styles:

1. The *efficiency* style (F (2,133)=9.34, p<0.001, $\eta_p{}^2$=0.12), was found to be higher when compared to the *radical* innovator's style (M=3.95) and lower when compared to the *incremental* innovator's style (M=3.49). We did not find a significant difference between the *radical* as well as the *incremental* styles and the students who were identified as having an *architectural* innovator's style (M=3.72).

2. The *conformity* style (F (2,133)=4.64, p<0.05, $\eta_p{}^2$=0.07), was found to be higher when compared to the *radical* innovator's style (M=3.56) and lower when compared to the

incremental innovator's style (*M*=3.26). We did not find a significant difference between the *radical* as well as the *incremental* styles and the students who were identified as having an *architectural* innovator's style (*M*=3.32).

3. The *originality* style (F (2,133)=4.56, p<0.05, η_p^2=0.06), was found to be higher when compared to the *radical* innovator's style (*M*=3.78) and lower when compared to the *incremental* innovator's style (*M*=3.50). We did not find a significant difference between the *radical* as well as the *incremental* styles and the students who were identified as having an *architectural* innovator's style (*M*=3.73).

In sum, we found that students with a radical innovator's style inclined more than students with incremental innovator's style towards the three creative cognitive styles. However, the students with the architectural innovator's style inclined only moderately towards the three creative styles, but not significantly.

A sample of ideas

Through the IGI questionnaires in our study, the students generated approximately 900 innovative technological ideas. Before going into the results of employing the tool, here are some examples of the technological ideas that some participants have generated through the IGI questionnaire. We believe it illustrates what we will be referring to in the following results' chapter.

Ideas for problem 1: *Preventing Road Traffic Accidents*.

Each year one million people are killed in road traffic accidents worldwide. If a million people would have died from an illness, it would have been defined as a global epidemic. In this problem, participants were asked to suggest innovative solutions related to the various aspects of safe driving.

- *Collision Prevention*: A transmitter and a server. A System that controls the steering of the vehicle. Any vehicle on the road is fitted with such a system, and holds a unique identification code. The vehicle regularly transmits its unique code, and at the same time receives transmissions from surrounding vehicles, whilst the central server calculates their position. The central server is constantly monitoring that distances of the surrounding vehicles are reasonable. Where distances are unreasonable, automatic adjustments to the course and speed of the surrounding vehicles are made to prevent the risk of collision. Adjustments are performed by a *specially designed algorithm* to be developed. In large vehicles, two transmitting devices at two different corners will be installed.
- *Distance Measuring Radar, with breaking capability*: A satellite coordinated sensor installed in vehicles, designated satellites, and a control vehicle, which will operate alongside the sensors. Sensors in various vehicles on the road will communicate with each other, and calculate through satellites the distance and speed of the vehicle and of those around it. Sensors will review the routes of the vehicles and will be able to take control of steering and braking to prevent accidents, even before the driver becomes aware of the danger.

Ideas for problem 2: *Alternative energy sources.*

The need for energy in the developed world for personal use or energy hungry industries is increasing. Nevertheless, there is a growing awareness for clean energy. The participants were asked to generate innovative ideas for new resources, which are greener and safer.

- *Ultra Magnus*: A huge ring that surrounds earth outside the atmosphere, so that its diameter is the diameter of earth plus some 300 kilometers (twice the height of 100 km from earth around the edge of the atmosphere, within the ionosphere). The ring will remain around earth due to its gravity. The earth's rotation will produce a magnetic field, which may be used to generate free energy, in a way, similar to the operation of a rotor in an electric motor, using the magnetic properties of the poles. A control system will prevent damage by aircrafts departing from earth (satellites and missiles exiting the atmosphere) and damage by meteors and asteroids. High efficiency (large surface area) solar receivers will be installed on the outer circumference of the ring and on its sides and will generate cheap electricity and energy, regardless to the magnetic field, whilst utilizing properties, such as the earth's magnetic field and energies form the sun.

- *Flexible Solar Cells*: A tapestry of solar cells, light-weighted and foldable, capable of being cut to tailored made measurements. The unit could be deployed on the roofs of apartment buildings or used for sheds on balconies. The solar unit produces electricity for the benefit of the living unit. The above solar unit will be available and cheap to buy. Customers will be able to easily deploy the solar surface in their house, balcony, courtyard, rooftop, or install it to shield a yard. It will be possible to connect the unit to an adapter, which connects to the home's electrical system and provide electricity thereto.

Results

In addition to examining the levels of innovation embedded in the ideas that were generated by the participating students, we also examined whether it is possible to define the cognitive types of innovation that represent this random sample of students. For that we examined the joint distribution (scatterplot) of the extent of change in the *components* of the ideas, compared with the extent of change in their *architecture* (Figure 3).

Figure 3. Joint distribution of innovative ideas in their components and architecture.

Figure 3 shows that the level of innovation in the development of innovative technological ideas that were generated by the students is strongly related to their *components* and *architectures'* dimension. A low level of change in the *components'* dimension is related to a low level of a change in the *architecture's* dimension and this is true also to high levels of change. We also found that the correlation between the extent of change in the *components'* dimension and the *architecture's* dimension of the idea to be very high (r (143) = 0.91, *p* <0.001).

In an attempt to calculate the correlation between the Architectural Innovation Model (AIM) of Henderson & Clark (1990) regarding the level of innovation in technologies with the results of this study, the students were divided based on the median of their *high* and *low* scores by the *components* and *architecture*'s dimensions (Table 3).

Table 3. Distribution of levels of innovation based on the level of change in the components and architecture's dimensions.

Table 3 illustrates the strong correlation between the change in components and the change in architecture. Most students were found either low in both dimensions, or high in both.

Consequently, and according to the results found, we can say that there are three main cognitive types of technological innovators:

1. Radical innovators (*high* in architecture and in components),
2. Incremental innovators (low in architecture and in components), and

3. Architecturally innovators (low in components, but high in architecture).

It seems that most of the students participating in our study were the radical and incremental types.

It would seem also that there is congruence between these findings and the Architectural Innovation Model (Henderson & Clark, 1990), upon which our IGI tool relies. Moreover, in order to examine the differences in the cognitive types of innovators, we have conducted a one-way analysis of variance multivariate (one way MANOVA) and indeed found a significant result ((F (4, 274) = 64.26, p <0.001, ηp^2 =. 27).

The one-way analysis of variance, undertaken in order to examine the differences in both indices of the study, i.e., the level of innovation in developing technological ideas and the potential for their implementation, also shows unmistakable results.

With reference to the level of innovation in developing technological ideas (F (2,138 = 178.34, p <0.001, ηp^2 =. 72), we found that amongst students, defined as the radical types (M = 3.70, SD = 0.39) the level of innovation is higher than in those defined as architectural types (M = 3.11, SD = 0.15), and in both the level of innovation is higher than in those defined as the incremental types (M = 2.61, SD = 0.28).

With reference to the potential and prospects of implementing the ideas (F (2,138) = 13.37, p <0.001, ηp^2 = 0.16), we found that among those students defined as the incremental types, the potential for implementation is higher (M = 3.21, SD = 0.56) than that, amongst students defined as the architectural types (M = 2.65, SD = 0.52) or as radicals (M = 2.75, SD = 0.55). The results of this analysis are shown in Figure 4.

Figure 4. Innovative thinking as a function of cognitive types of innovators

Discussion

The purpose of this study, as stated earlier, was to develop a tool that would be reliable to measure the potential of students from various engineering professions, to generate innovative technological ideas in major human problems. The tool, therefore, includes six global problems, which in the view of the participating group of experts in innovation they reflect much of the main challenges that high-tech industries will face in the future. The students that formed the research group were asked to formulate possible solutions to each of the problems they were presented with, referring to two dimensions in the level of innovation – the *components* and *architectural* dimensions, compared with these dimensions in existing or similar technologies.

The IGI tool focuses on solving problems that are ill-defined, whose solution requires an inter-disciplinary holistic view, critical thinking and intelligent review of databases containing many alternatives. These properties, according to different studies (Newell & Simon, 1972), are of the main skills, required from employees in knowledge-based high-tech industries, engaged in optimizing existing technologies and in developing new ones.

In light of the results, it would seem that the IGI tool could be suitable for measuring innovative thinking capability in developing innovative technological ideas amongst students in engineering departments as sought for by the authors of the Innovation & Business Industry Skills Report (IBSA) (2006) and by the authors of the OECD Program for the International Assessment o f Adult Competencies (PIAAC) (2010).

It would also seem that the wide variety of issues, listed at the base of this tool, assists in the identification of general innovative thinking amongst students, rather than referring to the narrow field of study of each student.

As stated at the aims of the study, the scores, generated by the IGI tool helped in classifying each participant in one of the five levels of innovation defined by Henderson & Clark (1990):

1. The *absence* of innovation;
2. *Incremental* innovation (moderate change in components and in architecture);
3. *Modular* innovation (drastic change in components and a moderate change in architecture);
4. *Architectural* innovation (drastic change in architecture and a moderate change in components);
5. *Radical* innovation (drastic change in components and in architecture (Henderson & Clark, 1990).

We did not identify in this study any participant, who demonstrated no ability to innovate at all (level 1 at the IGI tool). It seems that the process of academic training does succeed in developing, amongst the young engineering students, springs of innovative thinking as stated in the PIAAC program (2010), in addition to the basic skills, of course, which brings students to choose engineering initially. It would seem that these are probably people who have a natural tendency for the development and creation of technological innovation.

At one end of the capability to develop innovative thinking, are students with innovative *incremental* thinking. In this study, approximately 44% of the participating students were classified as having *incremental* innovative thinking.

Incremental innovation is characterized by small changes in the course of developing a technological product or service (Benner & Tushman, 2003). Some consider incremental innovation to be very important (Porter, 1990) since it leads to the improvement and perfection of the properties of existing products that enables companies to stay competitive in the short term (Leifer et al., 2006). The 21st Century labor market prefers projects that are profitable in the short term (Bers et al., 2009), and therefore, employees with incremental innovative thinking are essential for high-tech companies to survive demanding markets.

Our study shows, at least from our random sample, that nearly half of the potential employees in high-tech industries could be of this type of thinkers.

At the other end of the capabilities to exercise innovative thinking, are students with *radical* innovative style of thinking. In order to formulate their ideas, they propose drastic change, both to *components* of existing technologies, as well as to their *architecture*.

In our study, approximately 45% of the participating students were classified as being *radical* innovative thinkers. Radical innovative thinking involves replacing new knowledge with existing knowledge, as part of the process to find a breakthrough idea (Garcia & Calantone, 2002). Innovative thinking of these types is characterized by great leaps from the existing technology, which enable radical change (Benner & Tuchman, 2003).

Implementation of *radical* innovative style requires a generation, or even several generations of development before a mature and profitable commercial product is adopted by customers, all whilst exposing the organization to many risks and unexpected challenges.

This kind of innovative thinking style enables companies and organizations to prepare for long-term economic growth (Leifer et al., 2006). Therefore, employees with *radical* innovative style are essential for high-tech companies in order to secure their economic future. As it seems from this study, at least from our random sample, nearly half of the potential employees in high-tech industries could be of this style of *radical* innovative thinking style.

Between the level of *incremental* innovative thinking style and the level of *radical* innovative thinking style, there are two other possible levels of innovative thinking styles:

modular and *architectural* innovative thinking styles (Henderson & Clark, 1990). The first involves a drastic change in the components of an existing technology with only moderate change in its architecture. The later involves a moderate change in the components of an existing technology with a drastic change in its architecture.

In our study we found only some engineering students with an *architectural* innovative thinking style (10%), and very few with a *modular* innovative thinking style (less than 1.5%).

In order to understand these low measures, it is possible that when students with *architectural* innovative thinking style approach problems that are ill-defined, although they rely largely on existing components of the technology, nonetheless they generate a new kind of integration between them and actually create a drastic change in its architecture.

This kind of thinking is compatible with one way to define creativity (Nevo, 1997). According to Nevo, creativity is the ability to respond to a given or developing reality in an original manner (i.e., creating something new or a quality product), involving novel use of known components. More specifically, of all aspects of creativity, the *architectural* innovative thinking style requires most of all a highly flexible mentality in order to succeed in proposing a variety of original ideas related to a given problem. This kind of mentality goes against the more common cognitive process, known as *fixation*, defined as the inability to see a problem from a different angle. One of its known tendencies is *functional fixation* (Duncker, 1926), defined as a mental blockage, barring the use of a given object in a new way, needed to solve problems. It seems that such blockage limits a person's capability to use existing components in a new context.

In this regard, it is possible that the *architectural* innovative thinker has difficulties overriding this mental blockage and dare to forget, i.e., be prepared to abandon concepts, theories or situations that block new thinking, which in turn create intellectual fixation. This capability is defined as one aspect of a skill termed *Melioration* (Passig, 2003). The *Melioration* skill is cognitively quite complex and it seems that only a small portion of the engineering students are qualified to undertake it at this stage of their professional development.

The same argument could explain, respectively, the very low percentage (1.5%) of students who were identified as having a *modular* innovative thinking style. It is possible that *modular* thinking may be naturally very difficult to process, since a change in the components of a technology necessarily leads to a new kind of integration between them. Thus they are no longer the same components. It seems that at least amongst our random sample of engineering students, only a few could create this kind of thinking.

Limitations

Alongside the importance of the findings of this study, it is necessary to consider a number of methodological limitations. First, most of the students who were included in the study were males. Although the profusion in the number of males in the study reflects their proportion among engineering students in Israel, it is nevertheless recommended that a deeper look into the question of gender related differences in the capability of innovative thinking is undertaken and a future research should examine a similar number of participants from both genders.

Also, one must further consider the issue of reliability. Although a high reliability was found in the index of the levels of innovation, only a moderate reliability was found in the index of the potential to implement the ideas. It is possible that the borderline reliability may be due to the sample in this particular study, which included students who have not yet been required to implement their ideas. As a result, it is possible that the different ideas they proposed had different levels of potential for implementation. It is recommended, therefore, to continue and examine the IGI tool amongst other groups of employees in high-tech companies.

It is also recommended to follow our group of students while they enter the work force and even further down the road, a few years later, as full time employees in their field of expertise.

In conclusion, this study demonstrated that the IGI tool could assist in identifying the type of an innovative thinker. At the beginning of the 21st Century, organizations are required to recruit workers from a variety of types, to promote their growth and goals (IBSA, 2006; PIAAC, 2010). This tool may provide an additional vehicle to better categorize workers and to better prepare them in dealing with their weaker innovative thinking aspects. The development and validation process of this tool strengthened the claim that unlike other tools, previously examining innovation capability through a self-reporting mechanism only, the IGI tool objectively measures innovative thinking amongst students, thus allowing screening of potential employees in as early a stage, as at the stage of their undergraduate studies.

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Measuring the style of innovative thinking amongst engineering students

Table 1. Summary of properties of tools, measuring Innovative Thinking

Criteria / Tools		Capability to undertake Teamwork (Self-Reporting)	Capability to Take Risks (Self-Reporting)	Capability to take Decisions (Self-Reporting)	Capability to Solve Problems (Self-Reporting)	Capability to Implement Innovation (Self-Reporting/Expert Assessment)	Capability to generate Innovation (self-Reporting)	Measurement of potential to implement technological Ideas	Measurement of Level of Innovation in technological Ideas
1	Kirton Adaptors and Innovators (KAI). Kirton (1976)	+	+	+	+	-	+	-	-
2	Individual Innovativeness (HJC). Hurt, Joseph & Cook (1977)	+	+	+	+	-	+	-	-
3	Individual Innovative Behavior Scale (IIBS). Scott & Bruce (1994)	+	-	-	-	+	+	-	-
4	Innovation Intervention at Work (IIW). Bunce & West (1996)	-	-	-	-	+ Self-reporting on efficiency of undertaken innovations	+ Reporting on a number of proposed innovations	-	-
5	Team Climate Inventory (TCI). West & Anderson (1996)	-	-	-	-	+	+	-	-
6	The Suggestion and Implementation of Ideas (SII). Axtell, Holman, Unsworth, Wall & Waterson (2000)	-	-	-	-	+	+	-	-
7	Individual Innovative Behavior (IIB). Kleysen & Street (2001)	+	+	+	+	+	+	-	-
8	Innovation Work Behavior (IWB). Janssen (2000, 2001)	+	-	-	+	+	+	-	-
9	Team Innovation (TI). West, Borril, Dawson, Brodbeck, Shapiro & Haward (2003)	-	-	-	-	+ Assessing levels of innovation in ideas, proposed by Experts, using Indicators	+ Describing innovations proposed by groups of employees	-	-
10	Innovative Behavior (IB). Krause (2004)	+	+	+	+	+	+	-	-
11	Ideas Generation Implementation (IGI). The tool proposed in this current paper	-	-	-	-	-	-	+ Assessing ideas by Experts; an indicator from the	+ Generating technological ideas, as a solution to global problems; an indicator from the field of measurement of innovation in

Table 2. Averages and standard deviations of the most important technological fields in need of innovation.

	Problems in need of innovation	SD	M	%
1.	Preventing Road Traffic Accidents	1.48	9.07	90.0
2.	Generating Energies in Alternate Ways	1.30	9.03	88.3
3.	Improving and Optimizing Disease Diagnosis	1.27	8.95	78.3
4.	Improving Functionality of the Physically Impaired	1.27	8.77	83.3
5.	Solving Air Pollution Problems	1.48	8.55	81.7
6.	Solving Water Sources Pollution Problems	1.84	8.30	76.7
7.	Green and Smart Construction of Houses	1.79	7.63	53.3
8.	Locating and Identifying Criminals	1.85	7.47	53.3
9.	Securing Citizens in Public Places	2.25	7.46	49.2
10.	Solving Crowdedness and Congestion Problems	1.84	7.42	55.0
11.	Improving and Optimizing of Agricultural Produce	1.83	7.38	55.0
12.	Tech Tools for Improving Army Operations	2.45	7.23	55.0
13.	Preventing Earthquakes and Flood related Injuries	2.11	6.93	45.0
14.	Improving and Optimizing Car Travel	2.21	6.85	38.3
15.	Solving Urban Population Density	2.36	6.12	28.3
16.	Obesity Prevention in Children and Adults	2.65	5.87	30.0
17.	Improving and Optimizing Global Work Processes	2.12	5.86	25.4
18.	Improving and Optimizing Home Maintenance	1.82	5.60	11.7
19.	Leisure Time Technologies	2.39	4.95	11.9
20.	Improving Clothing for Daily Use	1.94	4.33	3.3

% indicates the percentage of members of the group of experts who voted for this technological field as one in need of innovation.

Table 3. Distribution of levels of innovation based on the level of change in the components and architecture's dimensions.

		Change in Components			
		Low		High	
		N	%	N	%
Change in Architecture	Low	64	44.14	2	1.38
		Incremental innovation		Modular Innovation	
	High	14	9.65	65	44.83
		Architectural innovation		Radical innovation	

Measuring the style of innovative thinking amongst engineering students

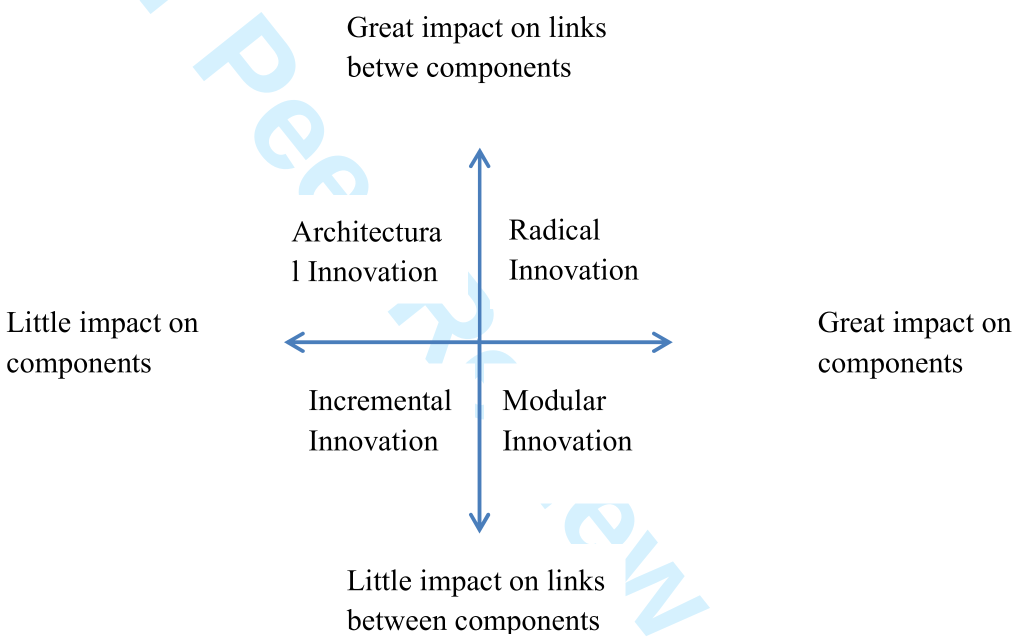

Figure 1. The Architectural Innovation Model (AIM) (Henderson & Clark, 1990)

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Figure 2. A sample page from the IGI questionnaire.

The purpose of this research tool is to measure conceptual innovation capacity in developing future technologies. The tool involves real life problems in different fields that can be resolved with new technologies or by improving existing ones. Also, the tool includes a number of questionnaires, aiming at identifying your cognitive profile as an innovator.

You are asked to propose ideas of innovative technologies, which may improve the quality of life in a number of defined areas. You may propose innovative and groundbreaking ideas, or ideas that uniquely and significantly upgrade existing technologies.

Please follow the following instructions:

- Each of the following 6 pages is dedicated to documenting one technological area in need of innovation.
- Clearly title an innovative technology idea in each of the areas.
- Describe the innovative unique components for each technology proposed.
- With reference to each idea, describe the innovative unique features, applicable for implementation.

Category 1: Preventing of Road Traffic Accidents

Title your Innovation: ____

General Description	A description of the unique and innovative components of the proposed technological product.
Clarify the innovation	Describe the innovative unique features and usages.
Clarify its applicability	Describe its applicability and the prospects of its implementation.

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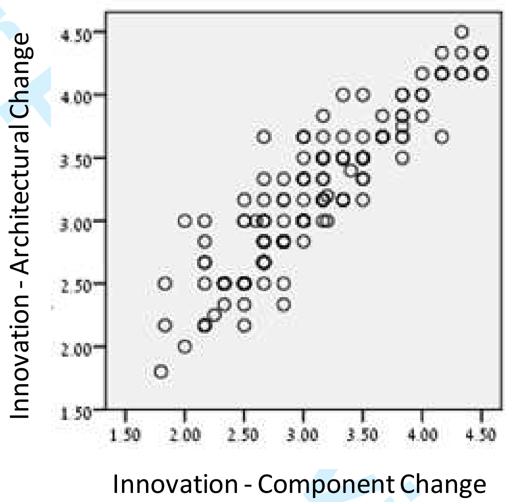

Figure 3. Joint distribution of innovative ideas in their components and architecture.

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Figure 4. Innovative thinking as a function of cognitive types of innovators