INTERNATIONAL ENGINEERING AND PRODUCT DESIGN EDUCATION CONFERENCE
2-3 SEPTEMBER 2004 DELFT THE NETHERLANDS

NON-HIERARCHICAL MIND MAPPING, INTUITIVE LEAPFROGGING, AND THE MATRIX: TOOLS FOR A THREE PHASE PROCESS OF PROBLEM SOLVING IN INDUSTRIAL DESIGN

V. Kokotovich

ABSTRACT
This paper discusses design strategies introduced to a group of 1st year industrial design students. The students were introduced to a three-phase design process which sought to mimic the design process/framework of expert designers. It will illustrate how existing methodologies were modified and staged in order to guide novice designers [students] in adopting the design problem solving processes/framework of expert designers. In general, the consensus of the students was that they had significantly altered their previous understanding and perspective of the design process by developing a detailed and rich appreciation for the complexity of issues found in design problems. In addition, this paper will propose ways in which these tools might be tested in a more empirical way.

Keywords: Educational methodologies,

1 INTRODUCTION
As the collective body of research relating to design theory grows, so does the need to reflect upon and alter the tools we use in educating industrial design students. When reviewing the literature that discusses various aspects of the design process, within the context of Industrial Design, a core activity of the process is creative problem solving. The design literature describes many varied strategies and tools, which assist designers in creatively solving design problems. When studying differences between expert and novice designers, Mathias [1] found novice designers were missing some important aspects in their process/framework when compared and contrasted with the problem solving process/framework utilised by expert designers. As highlighted in the Expert framework in Figure 1 below, it was suggested the elements missing were Analysis of Problem Statement, Convergence, and Solution Concept. The protocol studies of Ho [2], relating to problem decomposition strategies, lends further support to the view expert designers tend to establish problem structure at the beginning of the design process, stepping back from the brief contextualising the problem in their own way.
One responsibility of design educators is to move the thought processes of novice designers closer to the thought processes of expert designers. Therefore, it makes sense that mimicking the strategies of expert designers would enhance the creative output of novice designers. The work of Kokotovich [3] supported this view by conducting a series of experiments that investigated creative mental synthesis in designers and non-

designers. A core finding revealed when subjects separated ideas from the embodiment of ideas in the early stages of the design process, the level of creative output substantially increased for both the designers and non-designers. Consequently, introducing tools, which enabled first year industrial design students to forestall embodiment development and focus early on the complex issues surrounding a given problem, places them in a position to develop less pedestrian and more considered responses to that design problem. Additionally, introducing the students to other strategies and tools enabling them to move their design-thinking framework closer to the design framework of expert designers would be beneficial. The students should at the end of the semester be in a position to compare and contrast their previous design process with the newly developed strategies.

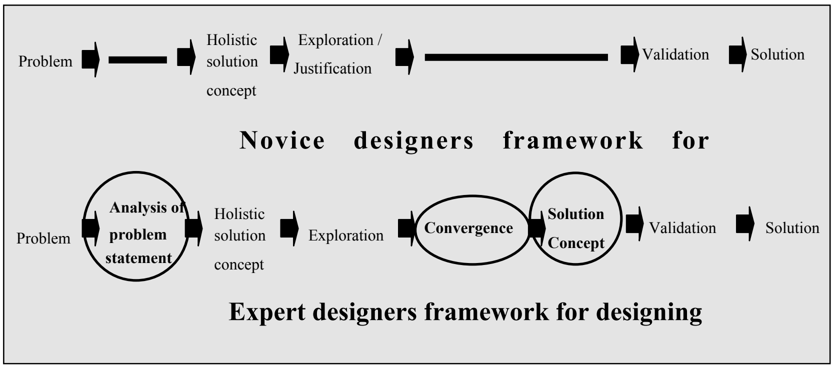

Figure 1. Expert & Novice framework for designing [based on Mathias (1993)]

The case study using first year industrial design students in their second semester of university study, reflects upon a few of these tools and utilises them in a three phase process. While a review of the design literature reveals the design process to be very complex, the expert's design framework found in Mathias [1] can be narrowed to a three-phase process for the first year students. Figure 2 below illustrates that in phase one the students were instructed in the use of non-hierarchical mind mapping.

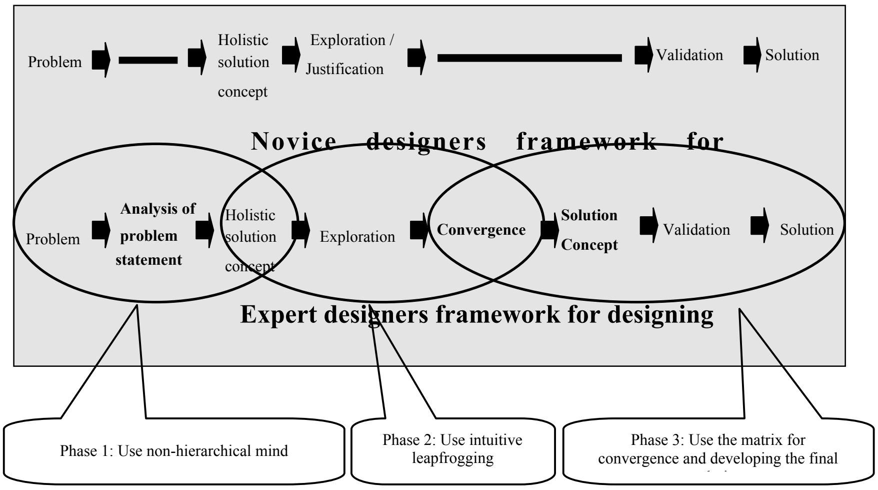

Figure 2. Three proposed phases of the Expert design framework

This assisted the students in developing a step relating to an analysis of the problem, in order to develop holistic solution concepts. Subsequently, in phase two, the students were introduced to the strategy of Intuitive Leapfrogging as a method for exploration. Finally, the students were introduced to the concept of using a Linkograph [Matrix] in order to facilitate Convergence, Solution Concept Development and Validation.

2 THE CASE STUDY

2.1 Background & phase 1 - analysis of the problem

In the second semester of the first year of studies within the Industrial Design program at the University of Technology Sydney, the students participated in a class entitled *Problem Solving in Industrial Design*. Throughout the semester the students were to complete four design projects, the first was the development of a coffee grinder. There are many types of coffee grinders utilizing a variety of physical principles that grind coffee for a variety of stakeholders. Consequently, the core requirements of the brief related to problem definition and problem analysis. In the second project the students were to creatively explore the concept of *People at Play*. This project required the students to work as teams in order to develop new and creative product concepts. The third project required the students to critically evaluate Candy/Bubblegum dispensers and develop a new design based on their critical review process. Forming the core of each of the first three projects were the strategies of Mind Mapping, Leapfrogging, and the Linkograph [Matrix] respectively. The fourth and final project required the students to use all of the strategies they were taught in the first part of the semester. The final design project required the students to integrate a plant oil camp stove and cooking utensils.

At the beginning of the first class, in order to determine their understanding of the design process, the students were asked to diagrammatically represent the design process. For the most part the processes described by the students paralleled the problem solving process/framework utilised by *novice designers*, and <u>not</u> the problem solving process/framework utilised by *experts* suggested in the research of Mathias [1]. Some of the students suggested adding a research task between problem and holistic solution development would assist in the development of a solution. They recommended that using a mind map could assist in structuring the problem. Once the students had completed discussing their diagrams, a lecture was given discussing the findings of Mathias [1] and Kokotovich [3] relating to the design process.

Picking up on the issues raised in relation to the use of mind mapping as a tool for researching/analysing the problem, it is suggested here that the hierarchical nature of mind maps may not be as beneficial as first thought in the context of their use as a tool for industrial designers. Mind mapping, generally accredited to being developed by Tony Buzan in the mid 1970's as a way of assisting memorising information, requires the participant to randomly note ideas and thoughts as they occur in relation to the problem at hand. In his more recent work Buzan [4] argues that the Basic Ordering of Ideas (BOI's) need to be placed in a hierarchical structure and then developed further. Drawing upon his book analogy, ideas can be structured as one would a table of contents in a very hierarchical structure [the book title leads to chapters- chapters lead to sections etc…]. From the perspective of industrial design this may be suitable for highly structured problems, however the design literature suggests that design problems are ill structured and ill defined [for example see Goldschmidt [5]; Lawson [6]; Dorst [7] Restrepo & Christiaans [8]]. By way of example, if the students were to use a hierarchical structure, figure 3 below would typify the Buzan [4] view of structuring the coffee grinder design problem.

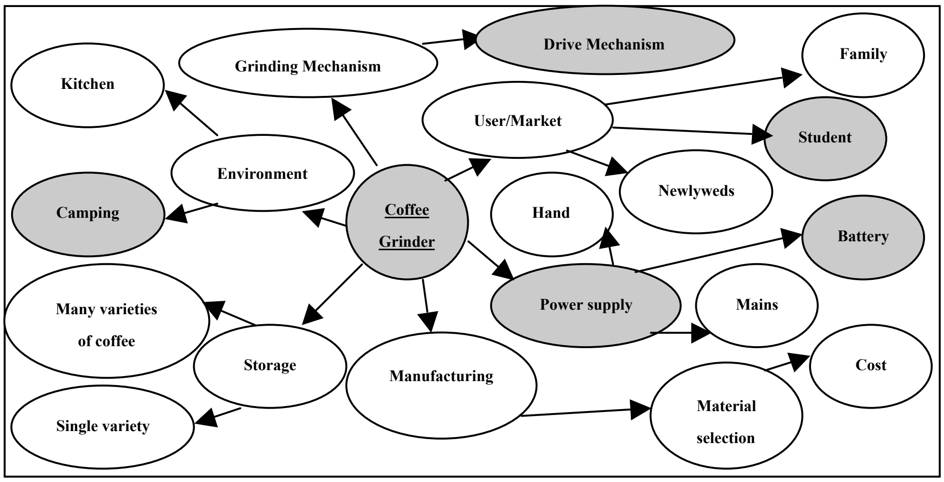

Figure 3. Hierarchical Mind Map [Coffee Grinder]

With respect to the first project, while using a hierarchical mind map can be considered a 'good start' in the development of a coffee grinder, it does not describe or demonstrate the important detailed interrelationships between and among the design issues to be considered. For example, if a scenario was envisaged by the novice designer that the chosen demographic was university students who wanted fresh ground coffee while on a camping trip, a technique should be available for the novice designer to show the interrelationship between and among the issues relating to the need for portability [camping] by user [student], the power supply [i.e. batteries or hand power] and the drive mechanism. These issues in turn impact upon the issues relating to manufacturing processes, and issues of material selection. It is suggested here that the basic structure of the mind map may be utilised with some enhancements in order to cope with ill structured problems.

As suggested earlier design problems tend to be ill structured and ill defined. Within ill structured design problems different types of associations exist between the issues. It is suggested that four basic types of associativity exist. They are as follows:

Unidirectional associativity [Represented by a single headed arrow] ⟶

Bidirectional associativity [Represented by a double headed arrow] ⟷

Unidirectional intermittent associativity
[Represented by a dashed line single headed arrow] -------▶

Bidirectional intermittent associativity
[Represented by a dashed line double headed arrow] ◀-----▶

Using the types of connections suggested above allows the designer to describe the important detailed interrelationships between and among the design issues. In addition, to arrow type connections, Color-coding/patterning of the issues and/or arrow types grouped into topics, themes, and sub themes, could further enhance a novice designers understanding and analysis of the problem at hand. Furthermore, the novice designer could add text explanations along the arrows and change the line weights in order to supplement an understanding of the interrelationships. Figure 4 below illustrates the use of the arrow coding in that the power supply intermittently uses the mains electricity, and intermittently powers the battery. However, the battery is always used to power the drive mechanism. Consequently, this use of a battery suggests direct bidirectional associativity between the battery power and the environment in which the grinder is used. In addition, due to the use of battery power, the environments in which the grinder is intermittently utilised are the kitchen or camping environments, therefore their connection to the battery becomes important.

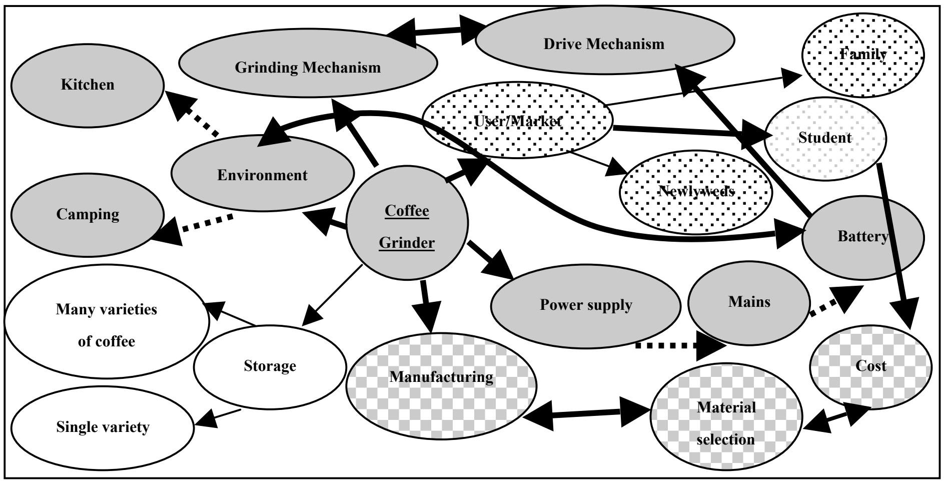

Figure 4. Non-Hierarchical Mind Map [Coffee Grinder]

Returning to the issue that a student is the intended user, in general it can be said that students have very little disposable income, consequently the cost of the coffee grinder becomes a factor. The cost has direct bidirectional associativity with the material selected in that cost impacts material selection and material selection impact cost. Further, material selection has a bidirectional associativity with both the environment the coffee grinder is used within and manufacturing issues, in that the use of a polymer suggests specific manufacturing processes while the use of a metal suggests other manufacturing processes. Additionally, the use of the coffee grinder outside suggests the need for a material that is robust and rugged.

As the students critically review and analyze the issues surrounding the design of a coffee grinder they begin to appreciate design problems are ill structured and generally do not have a hierarchical nature. As Buchanan [9] suggests design problems tend to be 'wicked problems'. When students develop very complex and intricate non-hierarchical mind maps they begin to critically review the design problem and move towards the thinking framework of an expert designer. While this work is not explicitly linked to the recent discussions of Oxman [10] relating to Think-maps, or Goldschmidt [5] discussing indeterminism and problem space, it can be seen as traveling parallel to it in that the novice designer must learn to make the connections between seemingly disparate bits of information and explicit knowledge. Consequently, the student learns to think deeply in relation to design decision and relationships.

2.2 Exploration - phase 2

The second phase of the process sought to move the thinking of the first year students closer to that of expert designers and introduced them to a strategy the author calls intuitive leapfrogging. However, prior to discussing the strategy it is appropriate that the exploration phase be contextualized. The creative mental synthesis experiments of Kokotovich [3] found greater numbers of creative responses were generated when the subjects were forced to develop ideas mentally and forestall the embodiment of ideas and drawing. Additionally, Mathias [1] found that novice designers tend to rush towards embodiments with undue haste and they tend to 'justify' their designs. This suggests they limit their creative search space. In order to explore a large number of divergent ideas the students would need a strategy that forces them to explore ideas that are 'unexpected'. In explaining the methodology to the students they were first exposed to an exercise in class. The first five students sitting in the first row in the lecture theatre were asked what was the first object/product that came to mind. These were sequentially noted on the white board in front of the room. For example, the first student could have said Motorcycle helmet, the second student surfboard, the third student mobile phone, the fourth said wine cooler and fifth student Television set. Next the topics were leapfrogged in that every other topic was connected. The student who thought of the motorcycle helmet was to develop a concept for a helmet and a mobile telephone. The second student had to leapfrog and conceptualise a surfboard with a wine cooler. The diagram in figure 5 illustrates that each topic is leapfrogged in order to force unexpected combinations and unexpected ideas.

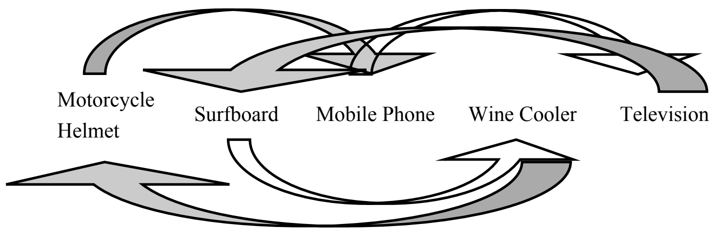

Figure 5. Intuitive Leapfrog

In the context of the second project [People @ Play], the students, in groups of four or five, were to use leapfrogging to explore the notion of play. The students were encouraged to collectively develop lists of topics that could be randomised. For example they could devolp a list which related to various play environments, a list of various types of play, various demograhics of people who play etc… Subsequently by dividing the lists and placing each item from the list on a card, they could randomise all their lists and 'pick them out of a hat'. Thus they could end up trying to conceptualise a group of busnissemen playing a team sport at a bus stop waiting for a bus. Alternatively, they could try to conceptualise Grandma and Grandpa playing a competative game of skill, underwater. The leapfrog effect forces unexpected ideas and concepts thereby offering opportunities for creative insights on the part of the design student.

2.3 Convergence and Solution Concept - Phase 3

As noted earlier Mathias [1] suggested the elements of Convergence, and Solution concept were missing. In order to achieve a holistic final solution concept, which is in need of validation, a structured methodology [such as using a weighted matrix system], would assist the novice designer in developing the missing convergence phase. Linkography is a structuralist research approach. While Goldschmidt [11] and van der Lugt [12] use linkography as a method of investigating protocol studies, here the linkograph is used to force the students to develop weighted interrelated links as part of the critical review and development process. In the third phase of the design process the students were instructed in the use of a Linkogarph [Matrix] in order to structure their ideas, concepts and issues. While the concept of using an interaction matrix [see Takahashi [13]] in order to structure the core design issues such as Human Factors, Mechanical operations, Space factors, and Environmental factors, is not new. The observation here is that it seems to have an advantage over other strategies in that it greatly assists in moving the designs towards convergence. Consequently, the students were guided in the use of this tool when given their third project, which required them to develop and evaluate Candy/Bubblegum dispensers in order to practice convergence. As an example, Figure 6 below serves to illustrate how a student might structure and weigh different design factors and issues in order to converge on a concept direction for the development of a bicycle in lieu of a Candy/Bubblegum dispenser.

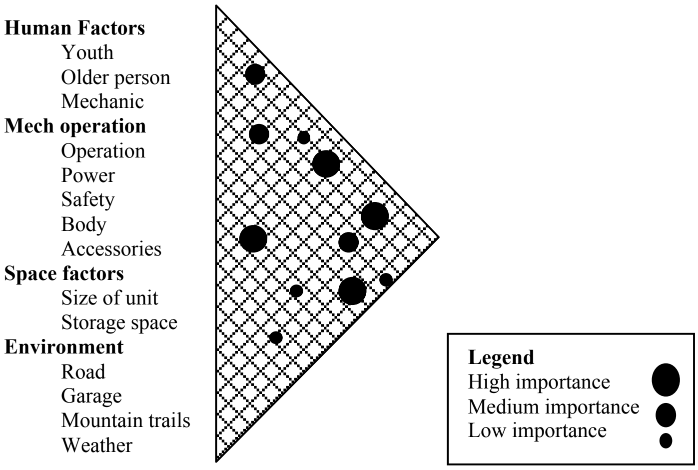

Figure 6. Linkograph [Matrix] of a Bicycle

The legend in Figure 6 above indicates, via size, the weighting placed on a relationship nexus in the matrix. In lieu of graphic indicators, numbers could be used, which in turn would allow the novice designer to develop mathematical weightings of issue connections. Consequently, a design solution direction would emerge guiding the novice designer towards a final solution. As an example, if the bicycle were for a youth market, the issues relating to accessories that enable the rider to perform tricks would be linked and highly weighted, in sharp contrast with developing a bicycle and accessories for grandparents.

3 CONCLUDING REMARKS

At the end of the semester, as part of their teaching quality assurance strategy, the University of Technology Sydney administers a Subject Feedback Survey [SFS]. The results of this survey were obtained and reviewed in order to investigate student views in relation to the subject *Problem solving in Industrial Design.* In general, the consensus of the students was positive in that they had significantly altered their previous understanding and perspective of the design process by developing a detailed and rich appreciation for the complexity of issues found in design problems. In addition, they found the tools/strategies useful and helpful in the development of their solutions to the design problems presented. They also realised some of the gaps in their previous design process/framework. Some of the qualitative data [comments from the students] is highlighted below.

"I liked the exploration and ideation of concepts and ideas and the development of product statements into effective products. The strategies and project stages, techniques involved in the assessments."
"I liked the depth of thinking this subject forced me to do"
"I liked the different interpretations of documenting the design process."
"I like the way the subject guides us to become a professional designer. The way it makes us think about issues or methods of design that I have never thought of."

While this paper illustrated how novice designers might be given tools/strategies in a three-phase process enabling them to develop a design process/framework similar to that of an expert designer, it is acknowledged this case study remains classified as being anecdotal evidence. This notwithstanding, it has illustrated how some existing strategies can be contextulised and utilised in an educational setting in order to advance the students' understanding of an evolving design process.
In order to test, in a more empirical way, the ideas highlighted in this paper, a suggested way forward would be to use groups of first year industrial design students drawn from various Universities. This would increase the sample size. Subsequently the students would be randomly placed into one of two cohorts, one in which the strategies were taught and the other a control group, who would be unaware of the strategies suggested in this paper. It is envisaged both cohorts would be given a design project, over the course of one day that would allow the researchers to compare and contrast both the design process/frameworks and the design outcomes. Concurrent Protocol analysis would be used to track the different design process/frameworks. A panel of expert industrial design academics would judge the subsequent designs. The judges would be blind to the strategies used. The designs would be rated in terms of creativity/originality and the depth of resolution. The panel would be asked to identify which designs they considered to be generated by expert designers. Subsequently, both qualitative and quantitative empirical data could be gathered for analysis, thereby adding to our understanding of design thinking and design education.

ACKNOWLEDGEMENTS
The author gratefully acknowledges the participation and feedback from the 1St year students who endeavored to develop their creative problem solving abilities using strategies discussed in this paper.

REFERENCES
[1] Mathias, J. R., *A Study of the Problem Solving Strategies used by Expert and Novice Designers*. Thesis (PhD). University of Aston, Birmingham, UK, 1993.
[2] Ho, C., Some phenomena of problem decomposition strategy for design thinking: differences between novices and experts. *Design Studies*, 22, 2001, pp 27-45.
[3] Kokotovich, V., *Creative Mental Synthesis in Designers and Non-designers: Experimental Examinations*. Thesis (PhD). University of Sydney, Sydney, Australia 2002.
[4] Buzan, T., *The Mind Map Book*. BBC Books, London, 1995.
[5] Goldschmidt, G., Capturing indeterminism: representation in the design problem space. *Design Studies*, 18, 1997, pp 441-455.
[6] Lawson, B., *How Designers Think*. Architectural Press, Oxford, 2000.
[7] Dorst, K., Creativity in the design process: co-evolution of problem-solution.

Design Studies, 22, 2001, pp 425-437.
[8] Restrepo, J. and Christiaans, H., Problem Structuring and information access in Design. In: Proceedings of the 6th Design Thinking Research Symposium: Expertise in Design, University of Technology, Sydney, Australia, 17th – 19th November 2003, pp 149-162.
[9] Buchanan, R., Wicked problems in design thinking. *Design Issues*, 8, 1992, pp 5-22.
[10] Oxman, R., Think-maps: teaching design thinking in design education. *Design Studies*, 25, 2004, pp 63-91.
[11] Goldschmidt, G., The Designer as a Team of One, In Cross, N., Christiaans, H., and Dorst, K., (Eds) Analysing Design Activity, Wiely, Chichester,1996 pp. 65-91
[12] van der Lugt, R., Relating the quality of the idea generation process to the quality of the resulting design idea. In: International Conference on Engineering Design ICED 03 Stockholm August 19-21, 2003
[13] Takahashi, M., *From Idea to Product, The integrated Design Process*. Hong Kong Productivity Council, Hong Kong, 1999.

Contact Information:
Dr Vasilije Kokotovich,
Industrial Design Program,
Faculty of Design, Architecture & Building
University of Technology, Sydney
P.O. Box 123,
Broadway, NSW, 2007
Australia
Phone: +61 2 9514 8952
Fax: +61 2 9514 8787
Email: V@uts.edu.au