Problem analysis and thinking tools: an empirical study of non-hierarchical mind mapping

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A review of the problem-solving literature related to design-thinking processes revealed that the problem-solving framework utilised by novice designers is missing some significant aspects when compared to the design-thinking framework utilised by expert designers. The central theme of this paper focuses on an early phase of the design process, more specifically, problem analysis and thinking tools that assist in problem analysis. Drawing on educational constructivist theory and concept mapping research found within the domain of cognitive psychology, this paper empirically investigates and discusses why non-hierarchical mind mapping tools are useful as design tools when introduced to a group of first year industrial design students. It illustrates how non-hierarchical mind mapping techniques can guide novice designers (students) in adopting the design problem-solving processes/framework of expert designers. Further, the experiments revealed statistically significant correlations and relationships between the analysis phase and the resultant creative output.

Keywords: conceptual design, creativity, design cognition, design education, thinking tools

A core responsibility of industrial design educators is to develop the thought processes of novice designers mitigating the transition towards the thought processes of expert designers. Within the context of Industrial Design, literature discussing various aspects of the design process reveals a core activity of the design process is creative problem solving. As research relating to design theory grows, so does the need to reflect on and alter the tools we use in educating industrial design students. However, as there are different aspects to the design process this paper will focus on an early phase of the design process, more specifically problem analysis and thinking tools which assist in problem analysis. As a result of his investigations comparing and contrasting the problems solving strategies of expert and novice designers, Mathias (1993) found that novice designers omitted some important aspects in their process/framework when compared and contrasted with the problem-solving process/framework utilised by expert designers. In the early phases of problem solving, as highlighted in the expert framework in Figure 1, it
was clear that a central element absent in the Novice designers’ framework was Analysis of Problem Statement.

As we endeavour to move the novice industrial designers thinking framework towards that of an expert industrial designers thinking framework, it makes sense that mimicking the strategies of expert designers would enhance the creative output of novice designers. Similar to the views of Mathias (1993), while acknowledging that problem structuring occurs throughout the problem-solving process, in their paper discussing problem structuring, Restrepo and Christiaans (2003) contend that problem structuring and analysis occurs mainly at the beginning of the problem-solving process. In his protocol studies relating to problem decomposition strategies, Ho (2001) lends further support to the idea that 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. Further, Restrepo and Christiaans (2003) assert there are differences in the way some designers approach problems. There are instances where designers develop abstract relations and concepts (they view this as being problem oriented); alternatively designers develop descriptions of the possible solutions (they view this as being object or solution oriented). This paper will focus on the former and not the latter.

1 Problem structuring

Problem structuring requires the designer to draw widely on knowledge and information flows in order to move towards and develop a solution. This is supported by the protocol studies of Cross (2003) where he sought to develop an understanding of the expertise of exceptional engineers and product designers. His study revealed three common design process aspects: (1) experts took a broad ‘systems approach’ to the problem as opposed to merely accepting narrow problem criteria; (2) experts framed the problem in a distinctive and personal manner; and (3) experts designed from ‘first principles’. These
aspects are consistent with the work of Mathias (1993), Ho (2001) and Restrepo and Christians (2003) in that prior to a designer developing abstract relations and concepts, a great number of design issues need to be raised and structured for a designer to develop a solution. Moreover, these issues are thought to be complex in that they are dynamically interrelated. Often novice designers overlook these complex dynamic relationships. Mathias (1993) found that novice designers tend to rush towards embodiments with undue haste and they tend to ‘justify’ their designs. This suggests that they limit their creative search space due to a limited understanding of the substantive issues relating to the design problem. It can be argued that they lack an appropriately comprehensive methodology or thinking tool for mapping these complex dynamically interrelated issues that result in an adaptable and malleable problem structure.

The impetuous novice designer, lacking a sound methodology for properly mapping their thoughts, ideas and the issues germane to the problem, rushes into an embodied solution early in the design process. Typically, novice designers refrain from ‘stepping back from the brief’; often they do not separate ideas from the embodiment of those ideas. This results in a tendency to develop less creative and more pedestrian solutions. It would be to their benefit to forestall embodiment of their ideas. The creative mental synthesis experiments of Kokotovich (2002) found that greater numbers of creative responses were generated when the subjects were forced to develop ideas mentally and forestall the embodiment of ideas and drawing. This was supported by empirical experiments that investigated creative mental synthesis in designers and non-designers. A central finding revealed that 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 enabling industrial designers to forestall embodiment development and focus early on the complex issues surrounding a given problem, places them in a position to develop more considered responses to that design problem. Therefore, introducing industrial designers to problem structuring strategies/tools would prove beneficial, moving their design-thinking framework closer to the design framework of expert designers.

This begs the question of where appropriate strategies/tools would be found. These strategies/tools would require an industrial designer to structure and map the salient issues, thoughts, and ideas relevant to the design problem in the early phases of the design process. Prior to a designer developing abstract relations and concepts, a great number of design issues need to be raised and structured for a designer to develop innovative solutions. Problem structuring requires the designer to draw on knowledge and information flows and diagrammatically map the information/issues in order to move towards and develop a solution.
Considered one of the founders of constructivist educational theory, Bruner (1960) in his discourse in relation to the importance of structure in the process of education argues that when students draw on personal accumulated knowledge and information, subsequently representing that knowledge, this in turn leads to understanding. Further, once a student has gained understanding of the fundamentals of a problem area, learning transference can more easily occur when the student is presented with a new and novel problem. Following on from this basic view of educational theory, Sutton (2003) describes and represents this iterative educational process in the form of a triad as in Figure 2.

When referring to Figure 2, Sutton (2003) sees the base of the triangle as forming the foundation of the problem-solving process in that the student draws on their previous pattern of experience making mental representations of that experience and different aspects of the problem. He asserts these activities work together to establish a complete understanding of the problem and its underlying structure. Further, the development of an understanding of the problem and its structure is by nature iterative and cyclical. An understanding of a problem does not occur sui generis. It occurs based on previous understandings, experiences, and associations. It is argued here that in order to more fully understand a problem, students should cycle through and map a large number of the issues relating to the problem in order to generate multiple perspectives of the problem. Subsequently, this mapping will assist the student in structuring both the problem and their individual understanding of the problem/issues prior to any embodiment of ideas.

2 Mapping issues and mapping tools
A growing body of design literature discussing the structuring and mapping of the design process is steadily increasing. While this work is not explicitly linked to the recent discussions of Oxman (2004) relating to Think-maps, where she investigated the use of Web based tools in order to develop the thinking

![Figure 2 Problem solving triad: key components in the problem-solving process and learning transfer process (based on Sutton, 2003)](image-url)
processes of design students, or the work of Goldschmidt (1997) and her dis-
cussion of indeterminism and problem space, it can be seen as travelling parallel to it in that the novice designer must learn to make the connections between seemingly disparate bits of information and explicit knowledge. Consequently, it is argued that students learn to think deeply in relation to design decision and relationships. In her work, Oxman (2004) grounds her work in constructivism and concept mapping. While Oxman (2004) provides a methodology for structuring issues, concepts, and forms, the notion of allowing forms or embodiment in the early phases of the design process may offer an opportunity for students to limit their creative search space as discussed above. This notwithstanding, she does develop a strong case for the use of concept-mapping techniques within the framework of the design process. Additionally, the more recent work of Visser et al. (2005) discusses mapping the contexts of people’s interactions with products and future products. While they make a strong case for using context mapping techniques in order to more fully understand possible products and product use experiences, their focus clearly relates to interaction experiences and not necessarily other issues within the context of problem solving.

2.1 Concept mapping

Following on from the discussion above, there is the need to widen the search for thinking tools for individuals and groups of people by moving into other domains such as the cognitive sciences. While there is no precise and agreed definition of cognitive mapping/concept mapping, the recent works of Eden (2004) and Yin et al. (2005) provide an appropriate background for this discussion. The work of Eden (2004) focused on analysing cognitive mapping/concept mapping techniques with the view towards helping users, both individuals and groups, to structure issues or problems in need of resolution. Eden (2004) asserts that cognitive maps are not simply words and arrow diagrams or influence diagrams. Further, he does not appear to regard the mind mapping/brain mapping discussed in Buzan (1995) as holding much utility. From a design perspective, some aspects of mind mapping may hold some utility for the design process. However, later we will discuss the limitations of Buzan (1995) in the context of hierarchical mind mapping. This notwithstanding, Eden (2004) argues that cognitive maps are not to be taken as models of cognition but as tools for reflective thinking and problem solving. Further, he sees the possibilities for mapping what he describes a discovery loops that offer opportunities to identify corresponding and connecting concepts. Subsequently, in essence, the maps have utility as conceptualisation maps, for solving ill-structured problems.

The work of Yin et al. (2005) empirically investigated two concept-mapping techniques. They compared and contrasted two experimental conditions. In one condition, subjects [students] are provided concepts and instructed to construct a concept map using self-created linking phrases. By comparison, in the
second condition, subjects [students] were to use a mapping technique in which they were supplied with both linking phrases and the concept terms. Consequently, the subjects in the second condition needed to select and assemble the concepts and linking phrases. They found that subjects supplied with the linking phrases in contrast to the subjects who created their own linking phrases tended to generate simpler concept maps and fewer dissimilar propositions. This has implications for concept mapping in the industrial design process in that if the designers were free to create and develop the dynamic interrelationships and the phrases, they should inevitably develop richer concept maps and dissimilar problems solutions, in contrast to being given issues and relationships to consider. In essence, the strategy has the potential to teach design students to be problem setters than problems solvers, moving them towards the design-thinking framework of an expert designer.

The above notwithstanding, while the designers may be free to generate their concept maps and are free to develop the linkages and subsequently the information relating to the linkages, limits to their graphic representations of the linkages may occur, as Yin et al. (2005) point to five different key concept-mapping structures. These structures have their limits in terms of utility for the design process. They described five structure types. These are as follows (refer to Figure 3): (1) Linear—issues and ideas that are sequentially linked together; (2) Circular—issues and ideas that are sequentially linked together with the ends joined; (3) Hub or Spokes—issues and ideas that derive from a centre concept; (4) Tree—a linear chain of issues and ideas that have branches attached; and (5) Network or Net—a complex set of interconnected issues and ideas. The network structure is seen as non-hierarchical and considered the most complex. Therefore, it is the richest in terms of assisting the

![Legend](image)

![Diagram](image)

Figure 3 Structure and complexity of concept maps (based on Yin et al., 2005)
designer in developing an understanding of the problem space and the
dynamic interrelationships among the design issues. Conversely, the linear
structure is considered the simplest and therefore the structure with the least
utility for developing design solutions. The other three fall in between in terms
of their utility.

2.2 Mind mapping

Earlier it was suggested that some problematic issues arise in relation to the use
of mind mapping as a tool for structuring/analysing design problems. It is sug-
gested 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. Re-
garding a technique for assisting memorising information, Tony Buzan is gen-
erally credited with being the chief architect and developer of Mind mapping
techniques in the mid-1970s. Generally, mind mapping requires the participant
to randomly note ideas and thoughts as they occur in relation to the problem
at hand. Highlighted in his more recent work, Buzan (1995) argues that the
Basic Ordering of Ideas (BOIs) need to be placed in a hierarchical structure
and then developed further. Using the book analogy of Buzan (1995), ideas
can be structured as one would a table of contents in a very hierarchical struc-
ture (the book title leads to chapters, chapters lead to sections, etc.). This has
resonance with the hierarchical tree structure found in Yin et al. (2005) and in-
dicated previously (highlighted in Figure 3). When looked at from the perspec-
tive of industrial design, this may well be suitable for highly structured and
highly defined problems; however, a review of recent design literature suggests
that design problems are ill structured and ill defined (e.g., Goldschmidt, 1997;
Dorst and Cross, 2001; Restrepo and Christiaans, 2003).

If the hierarchically structured approach indicated by Buzan (1995) were ap-
plied to mapping some of the issues related to the development of a vacuum
cleaner, as in Figure 4, it would reveal a number of problematic issues.

Using a hierarchical mind map can be considered a ‘good start’ in developing
a vacuum cleaner. However, it fails to describe or demonstrate the important
detailed interrelationships between and among the design issues to be consid-
ered. Nor does it offer an opportunity to describe, via text or graphic images,
the supporting rationale or complex symbiotic relationships between issues.

By way of example, if a scenario was envisaged whereby the chosen demo-
graphic was a professional who wanted to use the vacuum cleaner in a variety
of situations, a technique should be available for the designer to show the
interrelationship between and among the issues relating to the need for porta-
bility in a variety of contexts (environments) by the user (Professional cleaner),
the power supply (i.e. batteries or mains power), the drive mechanism, etc.
These issues in turn influence the issues relating to manufacturing processes,
and issues of material selection. Clearly, by following the hierarchical tree
structure mapping strategy suggested by Buzan (1995), the opportunity for the
description and graphic representation of the complex relationships between
these issues is lost. Consequently, the utility of hierarchical mind mapping is
low. It is suggested here that the basic structure of the mind map may be util-
ised with some enhancements in order to cope with ill-structured problems.

Earlier discussions indicated that design problems are considered to be ill struc-
tured and ill defined. Different types of associations exist between the issues
within ill-structured design problems. It is suggested here, as in Kokotovich
(2004), 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)

The types of connections suggested above permit the designer to describe
the important detailed interrelationships between and among the design
issues in a dynamic and evolving way. Additional and alternative coding
techniques may also be utilised. Colour-coding/patterning of the issues,
colour-coding arrows, and generating light and heavy arrows are also
helpful codification techniques. Grouping topics into themes, and sub-
themes could further enhance a designers understanding and analysis of
the problem and its concomitant issues. With the view to further enhance
and represent the designers understanding of the dynamically interrelated
issues within a given problem, number codes within bubbles along the
arrows, acting as referents for text explanations along the side of the map, will supplement an understanding of the interrelationships.

A review of Figure 5 illustrates the use of the arrow coding in that the vacuum cleaner needs a power supply (see issue note numbers 1 and 2) using the mains electricity, and intermittently powers the battery that may be housed in a portable vacuum cleaner (see issue note number 3). The arrow is unidirectional in that the mains supply always powers the battery, and the battery does not power the mains supply. Further, the battery consistently powers the drive mechanism (see issue note number 4). Accordingly, this use of a battery suggests direct bidirectional associativity between the battery power and the environment in which the vacuum cleaner is operated (see issue note number 5).

Due to the use of battery power, the environments in which the vacuum cleaner is intermittently utilised may be the kitchen or outdoor environments (see issue note numbers 6 and 7) therefore, the connection to the battery becomes important. Further, as the vacuum cleaner may be used outdoors,

Explanatory notes of issues:
[1] The vacuum cleaner needs a power supply
[2] May use the mains electricity supply
[3] Mains electricity supply may intermittently power/charge the battery
[4] The battery consistently powers the drive mechanism in addition the have a bi directional associativity
[5] Battery suggests direct bi-directional associativity between the battery power and the environment in which the vacuum cleaner is operated
[6] May be used intermittently in the kitchen
[7] May be used intermittently in outdoor environments
[8] When used outdoors different types and sizes of materials may be picked up and material may either be wet or dry
[9] Due to the pick up of wet or dry material, Vacuum unit material selection is important
[10] cost of the vacuum cleaner is seen as an investment therefore it is less a factor
[11] cost impacts material selection and material selection impact cost
[12] Material selection has a bi-directional associativity with both the environment the vacuum cleaner 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.
[13] The use of the vacuum cleaner by a professional suggests reliability and ruggedness are important
[14] Use in an outdoors environment suggests the need for a material that is robust and rugged

Figure 5 Non-hierarchical mind mapping

Problem analysis and thinking tools
this suggests that the different types of materials picked up by the vacuum need to be stored, and the material may either be wet or dry (see issue note number 8). This then suggests an emergent issue with respect to material selection (see issue note number 9). The storage unit needs to be waterproof.

As a professional cleaner is the intended user, it can be said that professionals take their job seriously. Consequently, the cost of the vacuum cleaner is seen as an investment, therefore it is less a factor in contrast to reliability and therefore represented as a lighter and ‘weaker’ line weight (see issue note number 10). This notwithstanding, cost has direct bidirectional associativity with the material selected in that cost impacts material selection and material selections impact cost (see issue note number 11).

Further, material selection has a bidirectional associativity with both the environment the vacuum cleaner 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 (see issue note number 12). Conversely, selecting a manufacturing process limits materials that may be used. Additionally, the use of the vacuum cleaner by a professional in an outdoor environment suggests the need for a material that is robust and rugged, thereby linking these issues to material selection (see issue note numbers 13 and 14). It should be noted that during the mapping/analysis phase of the problem-solving process (as above), embodiment is forestalled allowing a rich understanding of the problem space thereby enlarging the solution search space.

3 Applications to industrial design education

As students critically review and analyse the issues surrounding an industrial design problem, they begin to appreciate design problems are ill structured and generally do not have a hierarchical nature. Consequently, if they were to use the tree structured mind mapping suggested by Buzan (1995), the utility of such a strategy would appear to be limited. Conversely, when industrial design 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.

As a central responsibility of the industrial designer is to ‘tame’ technology for use by people, they essentially must develop a detailed understanding of the relationship between the nature of things and the nature of people. Consequently, in terms of developing and utilising non-hierarchical mind mapping tools, designers are encouraged to begin their mind mapping exercises by firstly depicting bubbles in the mind map that represent Who, What, Where, When, Why, and How (refer to Figure 6). These important core design issues/themes may easily be memorized by utilising Rudyard Kipling’s short little poem found below:
I keep six honest serving men
They taught me all I knew:
There names are What and Why and When
And How and Where and Who
(Kipling, 1993)

Mapping various aspects of Who, What, Where, When, Why, and How provides for the emergence of contradictions, paradoxes, and gaps in the information/design issues and/or various interpretations of the information/design issues so the designer may begin to make associations between those issues.

3.1 Experimental design
In the preceding discussions, it was argued that if the designer were free to create and develop dynamic interrelationships and the issues, they should inevitably develop richer concept maps and divergent problem solutions. This should result in more creative and considered final design solutions, as this design-thinking framework is similar to the design-thinking framework of an expert designer. Consequently, there should be a very high degree of correlation between designers who are able to raise and map these issues and their subsequent solutions, which are determined as being creative and well considered. To test this, an empirical experiment was developed and conducted. In the experimental design, the work of 33 volunteers from a class of 56 undergraduate students was used in the experiment. A naïve recruiter (recruiter blind to the experiment) was drawn from the School of Architecture, within the University of Technology, Sydney. They recruited first year
industrial design students completing the second semester Subject ‘Problem solving in Industrial Design’, within the Industrial Design program at the University of Technology, Sydney.

The students were given a semester long project that was divided into three separate ‘phases’ of the design process. In the first phase, as part of their subject, the students were briefed in relation to the following context. Each student was to individually define, identify and clearly articulate all the relevant and appropriate issues/problems that relate to the concept of @ Play. They were to fully contextualise these issues and communicate how these issues relate to each other in a dynamic way as applied to developing an appropriately innovative artefact or system for the concept of play. In addition, they were to explain how they relate to the industrial design problem-solving process in general. Further, the students were to imagine they were industrial design consultants who are briefing a client and explaining the issues they intended to resolve in developing a new and innovative artefact or system for play. The students were to utilise non-hierarchical mind mapping as a way to demonstrate the relationships.

The students were to develop a number of possibilities. However, ultimately each student was to develop and present one product proposal for further development and considerable refinement. Their product was to be fresh, innovative, appropriate, and yet be plausible. The students were expected to use non-hierarchical mind mapping as part of their design process and thereby parallel the design process of an expert designer by forestalling the embodiment of their ideas. The works of Kokotovich and Purcell (2001) and Kokotovich (2002, 2004) strongly support the notion of separating ideas from the embodiment of ideas in order to develop creative innovations and inventions.

The requirement to utilise non-hierarchical mind mapping will force the students to draw on their previous patterns of experience in order to represent their understanding of the issues and form associations in order to transfer that understanding in new contexts and new domains of knowledge. In essence, using non-hierarchical mind mapping requires the students to use old knowledge and understanding in order to develop new knowledge and understandings. This rests at the heart of constructivist educational theory and its application. It was suggested that the students could make use of existing mind mapping software. Not all mind mapping software available allows non-hierarchical links to be generated. Consequently, care should be taken in selecting the appropriate software. However, it can be argued that using the software may slow the momentum of ideas the student begins to develop as they raise and note the issues. Therefore, the students were encouraged to use a large sheet of paper to initially generate as many bubbles as they are able to and forgo making the links. Subsequently, they should re-create the bubbles using the mind mapping software and then develop the linking issues.
The work in Figure 7 is an exemplar drawn from a submission by one of the subjects. While the diagram does not represent the complete non-hierarchical mind map report, as it is one of the many maps the student generated, it represents a portion of this student’s understanding of the concomitant issues and problems related to play. Further, as the original image was generated at a much larger scale and considerably reduced here, while readability is somewhat limited, the imagery indicates both the breadth and depth of dynamically interrelated issues. The relationships were represented and explained in the text on the sides of the mind map.

This tool clearly assisted the student in both representing and structuring a great number of salient issues germane to the main design problem they were to solve. The process of generating the map and describing how the
student related and linked the issues forced the student to make associations among the numerous issues. Using a flexible mapping language allowed the student to construct their individual overall understanding of the problem, thereby developing an overall analysis of the problem.

After the students had mapped the issues relating to their @ Play brief, in the second phase of the project, they were to develop a number of creative conceptualisations using a number of creative thinking strategies taught to them as part of the subject. In the third and final phase of the @ Play project, the students were to use a linkography matrix to assist them in the convergence and validation solution development phase. Figure 8 is drawn from a submission by one of the subjects. It is an exemplar of how the students used linkography. It should be noted that the original image was generated at a much larger scale and considerably reduced here. Although it remains somewhat unreadable here, it serves to represent how the student approached the design process.

As noted earlier, Mathias (1993) suggested that 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 (first year industrial design student) in developing the missing convergence phase.

![Linkography Matrix](image)

*Figure 8 Sample of a first year ID student's linkography matrix*
Linkography is a structuralist research approach. While Goldschmidt (1996) and van der Lugt (2003) 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 linkograph (matrix) in order to structure their ideas, concepts and issues. While using an interaction matrix (see Takahashi, 1999) 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 such usage 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 developing their final proposed design solution for the @ Play project. The example in Figure 8 serves to illustrate how students were to structure and weigh different design factors and issues in order to converge on a concept direction as they draw from the creative conceptualisations they developed earlier in the second phase of the project. Consequently, a design solution direction would emerge guiding the novice designer towards a final solution. By the end of the semester each student had generated a presentation report for each of the three phases of the @ Play project.

Once the students completed the semester, the three reports from each of the 33 volunteer students were codified to mask the students’ identity. A total of five judges were recruited to review the student work. Each judge was an experienced industrial designer with five or more years of professional experience. Additionally, each judge has taught industrial design at the tertiary level. After the reports were codified, they were grouped into their respective phases (i.e. Phase 1 reports = mind mapping; Phase 2 reports = creative exploration and strategies; Phase 3 reports = convergence, validation and final proposal]. Each group of reports was placed into a different quiet room for review by the judges. Judging took place over two separate full days. A set of two judges reviewed the work on one day, and on the alternate day, a group of three judges reviewed the work. Each judge individually reviewed the students’ work in each room. While the students completed the @ Play project in three distinct ordered phases, the judges did not review the students’ work in this way. In order to eliminate any ordering effects in the research, judges were randomly selected to begin their review of the work in different rooms. That is to say, one judge may begin to review the final proposals of the students’ first report. Another judge would begin his or her review, in another room, starting to review the second phase or first phase of the students’ work.

Each judge had to rank and rate each report on two measures per report totaling six different measures. Figure 9 depicts the marking sheets and two measures for ranking/rating the mind mapping reports.
Given to each judge in each room were two ranking sheets, resulting in a total of six ranking/rating sheets from each of the five judges. For each measure, the judges were to review each student’s work and place it in a rank order from 1 to 33. Additionally, using a scale of 0 to 100, they were to give a rating score for that submission. Further, the judges were instructed not to have tie scores in their ratings to allow clear rankings to occur.

However, the focus of this paper is clearly the correlation relationship between the measures relating to mind mapping and the convergence/validation final proposals. Therefore, the relationship between four measures were empirically analysed in this paper. In the room containing the mind mapping submissions, the judges were to rank and rate the submissions in relation to the following:

- Rating of the quality and complexity of the clearly articulated dynamic interrelationships
- Rating of the number and quality of issues and themes raised and clearly articulated

In the room containing the submissions relating to convergence, validation and final proposal, the judges were to rank and rate the submissions in relation to the following:

- Rating of the creativity of the proposal and how well considered and detailed are its issues
Rating of the clear and reasoned analysis of the proposal and its validation against the issues raised

As the focus of this paper relates to comparing and contrasting the four measures above, the subsequent section will present the results relating to the data derived from the judgements.

3.2 Experimental results

The experimental design discussed above, resulted in a set of five ranking/rating judgements for each of the four measures relating to this paper. The five different rating scores from each judge for each measure were averaged. These averaged ratings were then rank ordered from the highest rating to the lowest rating. If as Amabile (1982) and Hennessey (1994) suggest creative responses determined via consensual agreement by ‘appropriate observers’ is reliable, then it is reasonable to use these rankings empirically examining correlations between the four rankings. In order to determine the degree of association between the different ranked measures, accepted statistical methods were used. The technique utilised was ranked differences correlation. The ranked differences were corrected for ties. While the instructions to the judges required that no tied scores should be given, when the scores were averaged there was a possibility of tied averaged scores to occur. Therefore, it was important to correct for tied scores.

In essence, this research tested the null hypothesis that two variables, ranks of scores by the set of judges, would not be associated \((H_0: r_s = 0)\). If the value of \(r_s\) is equal to or greater than the critical value for a given \(N\), then it is concluded that \(r_s\) is significant (one-tailed) at a \(p\) level indicated in a \(t\) distribution table. Correlation analysis using the rankings revealed the following results.

There was a statistically significant relationship at the 0.01 level when comparing the mind mapping—rating of the quality and complexity of the clearly articulated dynamic interrelationships with the mind mapping—rating of the number and quality of issues. Consequently, as the resultant \(t\) value for this relationship was equal to 20.66 and it was above the critical \(t\) value for \(df 32\) at the 0.01 level of 2.744, we may reject the null hypothesis. This suggests that the greater the number of quality design issues a designer develops, the greater the opportunity for the clear articulation of complex dynamic interrelationships between design issues in need of resolution. This has implications for the design process in that a detailed analysis and subsequent understanding of a design problem could offer greater creative and considered design solutions.

There was a statistically significant relationship at the 0.01 level when comparing the convergence, validation and final proposal—rating of the creativity of the proposal and how well considered and detailed its commensurate issues were with the convergence, validation and final proposal—rating of the clear and reasoned
analysis of the proposal and its validation against the issues raised. Consequently, as the resultant t value for this relationship was equal to 9.0046 and it was above the critical t value for df 32 at the 0.01 level of 2.744, we may reject the null hypothesis. This suggests that professional designers may more highly rate a proposal, which is creative, clearly reasoned and validated.

There was a statistically significant relationship at the 0.01 level when comparing the mind mapping—rating of the quality and complexity of the clearly articulated dynamic interrelationships of various design issues with the convergence, validation and final proposal—rating of the creativity of the proposal and how well considered and detailed its issues were. Consequently, as the resultant t value for this relationship was equal to 2.9464 and it was above the critical t value for df 32 at the 0.01 level of 2.744, we may reject the null hypothesis. This suggests that when a designer is capable of developing and clearly articulating design issues in need of resolution, this is linked to their capacity to develop creative and well-considered design proposals.

There was a statistically significant relationship at the 0.01 level when comparing the mind mapping—rating of the number and quality of issues and themes raised and clearly articulated with the convergence, validation and final proposal—rating of the creativity of the proposal and how well considered and detailed its issues were. Consequently, as the resultant t value for this relationship was equal to 2.9592 and it was above the critical t value for df 32 at the 0.01 level of 2.744, we may reject the null hypothesis. This suggests that if a greater number of clearly articulated themes/issues are raised, in the early stages of the design process, the greater the probability the final design proposal will be determined as being creative.

There was a statistically significant relationship at the 0.03 level when comparing the mind mapping—rating of the quality and complexity of the clearly articulated dynamic interrelationships with the convergence, validation and final proposal—rating of the clear and reasoned analysis of the proposal and its validation against the issues raised. Consequently, as the resultant t value for this relationship was equal to 2.4687 and it was above the critical t value for df 32 at the 0.03 level of 2.2746, we may reject the null hypothesis. This suggests that when designers are able to raise, consider and clearly articulate complex dynamic interrelationships between design issues, in the early stage of the design process, they are better prepared to present a highly regarded reasoned analysis of their final design proposal.

There was a statistically significant relationship at the 0.05 level when comparing the mind mapping—rating of the number and quality of issues and themes raised and clearly articulated with the convergence, validation and final proposal—rating of the clear and reasoned analysis of the proposal and its validation against the issues raised. Consequently, as the resultant t value for this
relationship was equal to 2.1974 and it was above the critical $t$ value for df 32 at the 0.05 level of 2.0395, we may reject the null hypothesis. This suggests that if there are a greater number of design issues raised in the early stage of the design process, designers are better prepared to present a highly regarded reasoned analysis of their final design proposal.

Given these results, Section 4 will serve to suggest some implications of these results.

4 Discussion and concluding remarks

Drawing on the above discussions, using non-hierarchical mind mapping techniques in the early phases of the design problem-solving process offers great utility for student designers, and perhaps expert designers. For example, large complex ideas, issues, propositions and associations are generated forcing the forestalment of the embodiment of ideas early in the design process, providing a greater opportunity for creative connections to occur between the issues and ideas. This moves the design-thinking framework of the designer closer to that of expert designers. Further, this research has suggested that a clear relationship exists between using non-hierarchical mind mapping and a designer’s ability to develop creative and reasoned product designs.

Owing to the graphical nature of non-hierarchical mind maps, the designer can comprehend the nature and structure of the problem/problems more readily developing a holistic approach in solving design problems. Opportunities unfold for the designer to integrate new and old information, ideas, issues, and material. Additionally, this allows the designer to develop and construct buildable bodies of knowledge related to the main problem and sub-problems, thereby generating an observable buildable record of the design process. In essence, they may act as memory aids for reviewing the problem/problems at any point in the complete design process.

Using non-hierarchical mind maps with notations relating to the linkages reveals meaning in the often complex embedded relationships in the design problems diagrammed, thereby allowing the designer to see both the ‘big picture’ and the minute details. Consequently, more detailed and subtler relationships may be mapped over time. Therefore, the designer has the opportunity to make creative connections between disparate seemingly unconnected domains of knowledge. Additionally, this assists the designer in finding new ways of constructing meaning within multiple design contexts and multiple domains offering the opportunities for more creative proposals.

The non-hierarchical mind maps also offer the designer structure without stricture in their design process prior to the exploration phase and the convergence phase of the problem-solving process, as it informs and offers the opportunity to assist in all phases of the problem-solving process. Moreover, the map may
act as a benchmark for the designer during the validation phase of the problem-solving process. A major and significant additional educational benefit of the non-hierarchical mind maps is that they allow the design educator to examine and guide the thought processes of the novice designer as they learn to analyse design problems, thereby moving closer to the design-thinking framework of expert designers.

It is clear that this research has empirically tested the utility of non-hierarchical mind maps in the early phases of the design process. As indicated earlier, these findings suggested that the greater the number of quality design issues a designer develops, the greater the opportunity for the clear articulation of complex dynamic interrelationships between design issues. This has implications for the design process in that a detailed analysis and subsequent understanding of a design problem could offer greater opportunities for more creative and considered design solutions. Further, this research suggested that the use of non-hierarchical mind mapping in the early phases of the design process is linked to the development of creative and well-considered design proposals. Additionally, it was found that if a greater number of clearly articulated themes/issues are raised, in the early stages of the design process, the greater the probability the final design proposal will be determined as being creative.

This research suggests that when designers are able to raise, consider, and clearly articulate complex dynamic interrelationships between design issues, in the early stage of the design process, they are better prepared to present a highly regarded reasoned analysis of their final design proposal. Additionally, it was suggested that if greater numbers of design issues are raised in the early stages of the design process, designers are better prepared to present a highly regarded reasoned analysis of their final design proposal.

While the findings revealed in this empirical study were based on novice industrial designers, this may have implications for our understanding of design thinking with respect to industrial design education and industrial design practice in general. To this end, the central findings tended to support the notion that thinking through and mapping the issues of a design problem prior to embodiment greatly assists in the convergence towards, validation of, and development of creative well-considered designs. Further, this empirical research can be extended to empirical investigations that assist in developing our growing understanding of these design-thinking tools and strategies. This notwithstanding, the next step should be an analysis of the data relating to both the first and third phases of the student project described in this study, and their relationships/correlations with the second phase of the student project.

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