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CASE STUDIES ON THE INFLUENCE OF THE DESIGN SCENARIO ON CONCEPT GENERATION

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1 Introduction

The engineering design process includes an expansive phase of "concept generation", in which potential solutions to a design problem are identified, followed by a contractive phase of "concept evaluation", in which the concepts are assessed and the preferred solution identified [1][2][3]. Exhaustive concept generation is critical to the design process, as:

- Any concept that is not identified prior to the evaluation phase cannot be a candidate for the preferred design solution, potentially limiting the quality of the design outcomes; and,
- If the designer chooses to develop a solution that is identified late in the design process, it necessitates a time-consuming reiteration of the design process.

A range of tools have been proposed to assist exhaustive concept generation, for example, brainstorming, synectics and morphological analysis [1][2][3], yet observation suggests that the concept generation process remains a creative process that is highly dependant on attributes of the particular design scenario [4].

2 Objectives

The objective of this work is to further understand the influence of the design scenario on the concept generation outcomes. To achieve this outcome, a novel sampling tool has been developed to document the important attributes of the concept generation process. The sampling tool has been applied to qualitatively assess the influence of a range of design scenario attributes on the concept generation outcomes in a series of case studies. This work allows the hazards and opportunities for exhaustive concept generation to be identified for a range of design scenario attributes. Based on this preliminary study, a series of proposals have been made to quantitatively assess the causal links between the design scenario attributes and the concept generation outcomes.

3 Methods

A sampling tool will be employed to record a description of each concept, and the time at which it was generated. Additional requirements of the sampling tool, and their associated importance, are:

- To minimise the influence of the sampling tool on the concept generation process> Specifically, the achievable rate of data acquisition, i.e., the “limiting rate”, should be maximised, importance = 4.
- The cost or the required sampling hardware should be minimised, importance = 3.
- The labour per sample should be minimised, importance = 3.

A series of sampling tools were proposed:

- Audio recording: The concept generation task is recorded in an audio format. The important attributes of the concept generation process are then documented by manual interrogation of the audio recording.
- Video recording: As for audio recording, but the documentation medium is video.
- Direct observation: The important attributes of the process are documented in-situ by a trained observer.
- Computer based: The important attributes of the concept generation task are input into a database by the designer.

A decision matrix was applied to assess the sampling tools according to the project requirements [1][2] (Table 1). Audio recording was used as the reference datum, to which the performance of the other sampling tools was assessed. According to the decision matrix, the performance of video recording is always less than the datum, due to the higher associated hardware costs. This scenario may change if the minimum requirements of the sampling tool were changed to include visual data, for example facial expressions. Direct observation also performs poorly, due principally to the low associated limiting rate. Direct observation is preferable for scenarios where the importance of hardware cost dominates. Of the sampling tools considered, the computer based sampling tool provides the best compromise between the project requirements for the current scenario (Table 1).

Table 1. Decision matrix of the proposed sampling tool versus the project requirements. The audio recording is the reference datum against which the other sampling tools are assessed.

Requirements	**Importance**	**Audio recording**	**Video recording**	**Direct observation**	**Computer based**
Maximise limiting rate	4	0	0	-10	-5
Minimal hardware cost	3	0	-5	+5	0
Minimal labour	3	0	0	-5	+10
		0	-15	-40	+10

Based on the outcomes of the decision matrix, a novel computer based sampling tool was developed to document the concept generation process. The sampling tool:

- Is self-administered by the designer. The designer is invited to respond to a series of visual cues and instructions that define the design scenario and prepare the designer for the required mode of data entry.
- Does not preclude direct observation. This may be implemented by initiating a concept generation task in a controlled environment with a trained observer.
- Allows a relatively high "limiting rate" of data acquisition, that is, the sampling tool permits rapid recording of ideas, with minimal influence on the concept generation process.
- Is highly flexible, and may be programmed to present a range of design scenarios; limit the allowable concept generation time; provide time-based cues to the designer.
- Provides in-situ analysis of the concept generation characteristics. This capability can be applied to modify any of the sampling tool parameters based on the response of the designer. For example, the concept generation task can be terminated when the concept generation rate drops below a specified threshold.
- May be distributed electronically.

3.1 General observations on concept generation characteristics

Once the sampling tool had been demonstrated as an effective means of recording the concept generation process, it was applied to examine the concept generation outcomes in a range of general knowledge based tasks. The observed concept generation characteristics displayed two distinct phases (Figure 1):

- A linear "burst phase", where the designer rapidly enumerates the concepts that, based on the designers experience, are immediately-evident solutions to the concept generation scenario. During the burst phase, concept generation occurs at a near constant rate; and,
- An asymptotic "exploratory phase", where concept generation is punctuated by concept-droughts, where no concepts are generated for an extended period. During the exploratory phase, the cumulative distribution of concept generation asymptotes towards the limiting value, or response-ceiling. Eventually the designer exceeds their "drought threshold", i.e. fails to generate a new concept within an extended time period and responds by terminating the concept generation process [5].

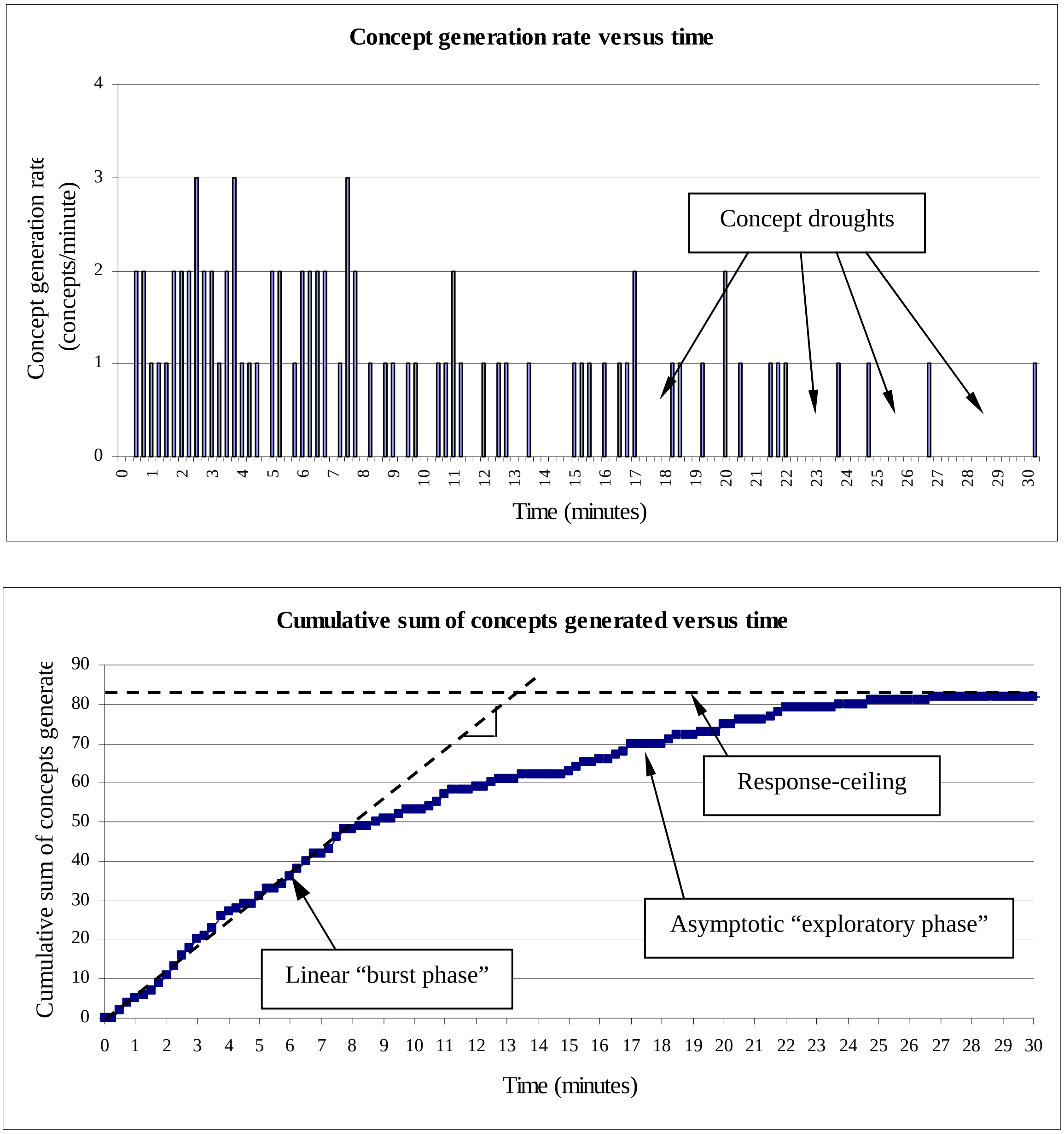

Figure 1. Outcomes of the computer-based sampling tool for a single designer responding to the concept generation task of Section 4.4. Upper: Concept generation rate versus time. Lower: Cumulative sum of concepts generated versus time. Typical features and nomenclature have been identified.

4 Assessment

A range of design scenario attributes were hypothesised to have a causal link with the concept generation outcomes:

- Concept generation time [4][6][7];
- The designers level of domain-specific knowledge [8]; and,
- The influence of a "gestation period" [2].

A series of concept generation scenarios were devised to quantitatively assess the influence of these attributes on concept generation. These scenarios were distributed electronically to a sample of undergraduate level university students. The data generated by the sampling tool includes:

- The designers level of domain-specific knowledge, as identified by self-assessment;
- Concept generation rate versus time, a 15 second sampling period was used; and,
- The cumulative sum of concepts generated versus time.

4.1 Concept generation time

As the intent of this work is to assist exhaustive concept generation, i.e. maximise the response ceiling, it is not advisable to terminate the concept generation phase before the designer concludes that further effort is unproductive. A scenario was developed to identify how a designer responds when the concept generation phase is extended beyond this internally generated response-ceiling.

This was achieved by presenting the designer with a concept generation task, with the stated objective of generating as many concepts as possible without time limit. Once the designer had completed the specified task, they were immediately requested to continue the task for an extended time period. General observations based on the response of designers to this scenario are (figure 1):

- The designer never terminates the concept generation process during the burst phase or the early stages of the exploratory phase.
- In the observed design tasks the drought threshold always exceeded the longest concept drought previously observed. For example, in Figure 2, the designer terminated the concept generation process after a concept drought of approximately two minutes, twice the duration of the largest concept drought previously observed.
- When the concept generation time was extended, the designer universally identified further concepts. The volume of concepts generated during the extended concept generation time is relatively low, for example Figure 2. However, these concepts were often the most innovative, and potentially the most valuable, of the concepts generated.

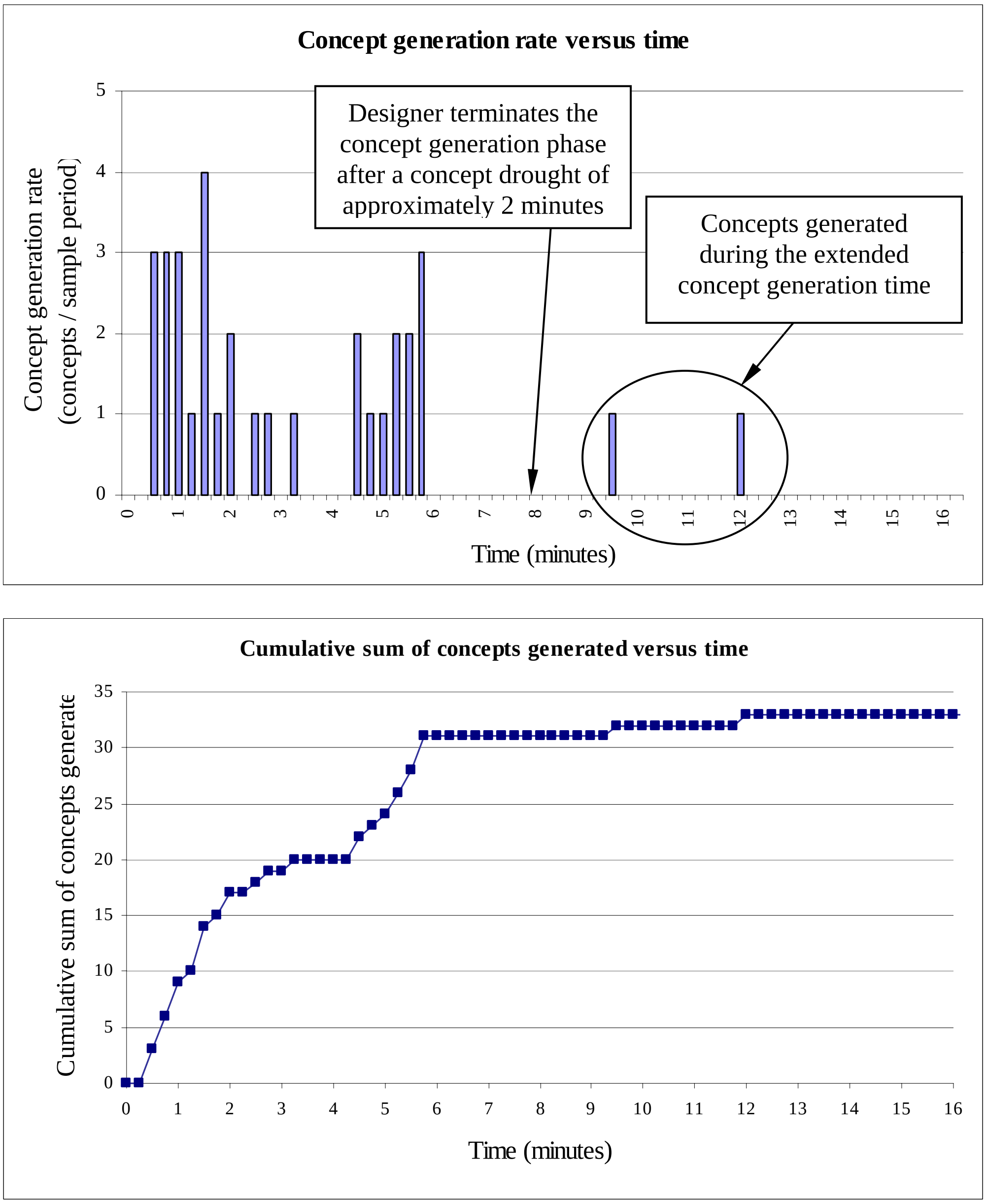

Figure 2. Sampling tool outcomes for a scenario devised to assess the influence of concept generation duration. Upper: Concept generation rate versus time. Lower: Cumulative sum of concepts generated versus time.

4.2 The influence of a gestation period

The sampling tool was modified to assess the influence of a gestation period, i.e. an extended pause in the concept generation task. This was achieved by repeating a concept generation task after a gestation period, in this work the gestation period was 24 hours. The designer was not advised that the design task would be resumed, but was allowed access to the concepts generated during the initial concept generation task.

It was universally observed that the inclusion of a gestation period increased the response-ceiling [6], even when the initial concept generation task includes an extended concept drought where no new concepts are generated (Figure 3).

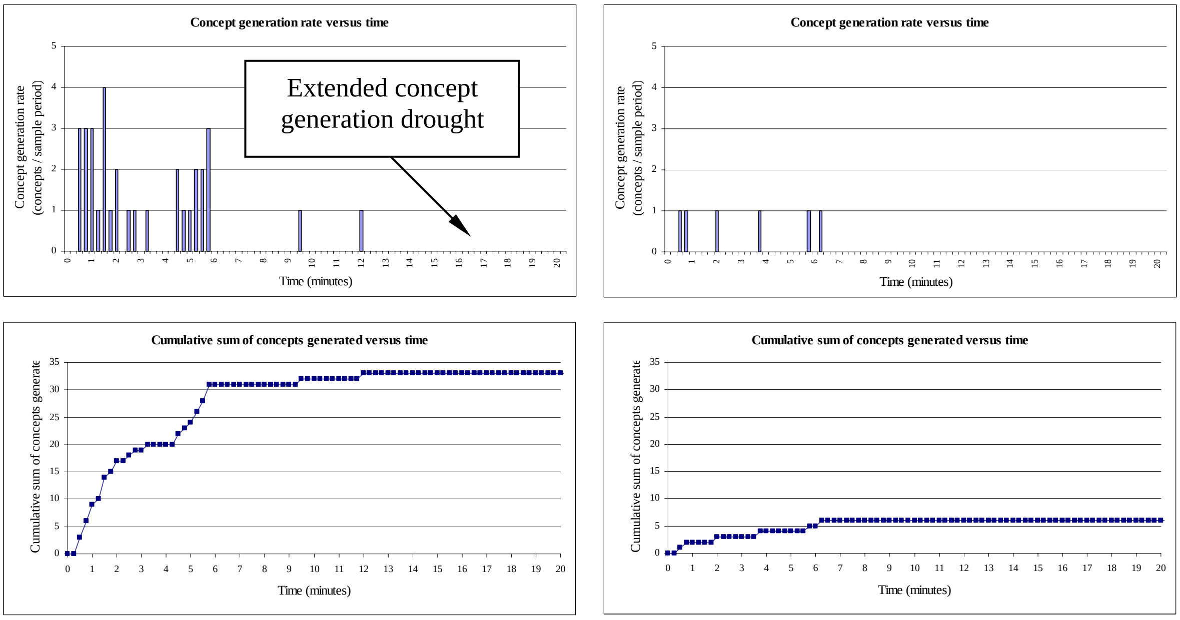

Figure 3. Sampling tool outcomes for a scenario devised to assess the influence of a gestation period. Left: Cumulative sum of concepts generated during the initial concept generation phase. Right: Cumulative sum of concepts generated after a 24-hour gestation period. Upper: Concept generation rate versus time. Lower: Cumulative sum of concepts generated versus time.

4.3 Domain-specific knowledge

The sampling tool was applied to assess the influence of domain-specific knowledge on concept generation outcomes. A series of concept generation tasks based on general knowledge were devised. The concept generation outcomes were compared for subjects with low and high domain specific knowledge. Figure 2 is indicative of the general observation that increased domain-specific knowledge results in an increase in the duration of the burst phase and an increased response-ceiling. The rate of concept generation during the burst phase appears to be independent of the level of domain-specific knowledge.

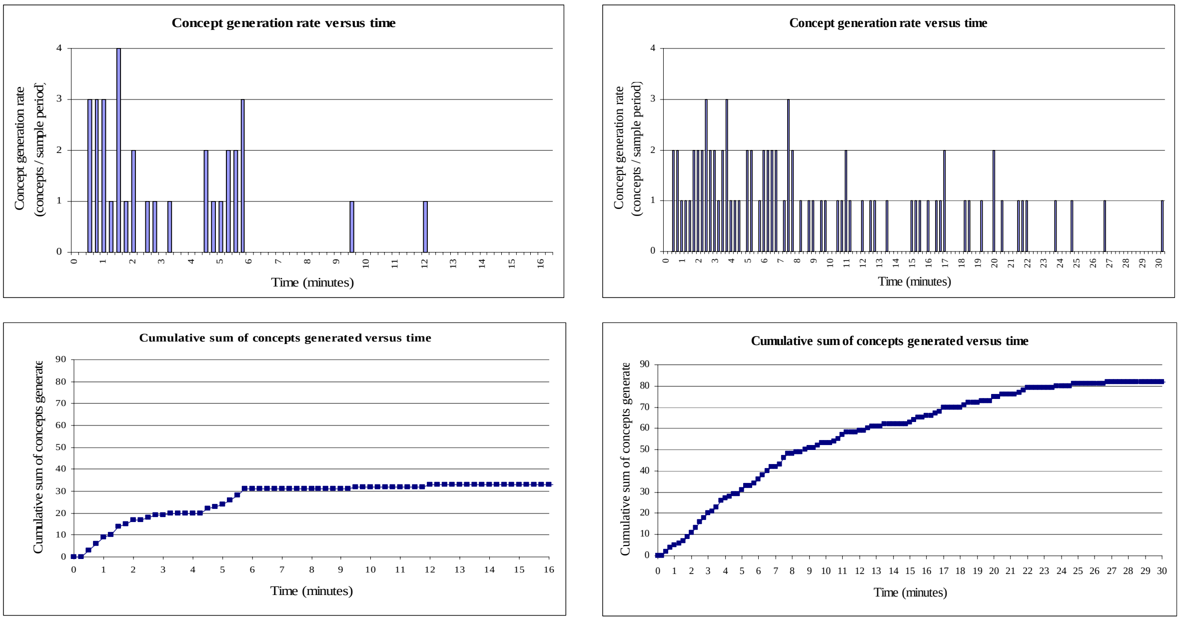

Figure 4. Sampling tool outcomes for a scenario devised to assess the influence of domain-specific knowledge.
Left: Low level of domain-specific knowledge. Right: High level of domain-specific knowledge.
Upper: Concept generation rate versus time. Lower: Cumulative sum of concepts generated versus time.

4.4 General observations on concept generation strategies

In observing the generic response of designers to a range of concept generation tasks it became apparent that the designer was applying an internal “search routine” to assist concept generation. Search routines suggested in the literature to assist exhaustive concept generation include: variant-design, morphological analysis and free-form ideation [1][2][3]. By observation of the response to concept generation tasks it was hypothesised that the dominant search routine was based on associative links between the successively identified concepts.

To assess this hypothesis a concept generation scenario was devised where the designer was requested to generate a list of as many capital cities as possible. This scenario allows the sequence and rate of concept generation to be physically linked with associated geography, potentially identifying the search routine applied by the designer to assist concept generation. The enhanced concepts generation techniques identified in this work were incorporated in this scenario, i.e. an extended concept generation phase and a gestation period.

Figure 5 indicates a case study of a designer with a low level of domain-specific knowledge responding to the proposed scenario. When the generated concepts were plotted sequentially on a world map, including data on the associated concept generation phase, a number of observations were made (Figure 5):

- During the burst phase the designer rapidly identifies the immediately-evident solutions to the concept generation scenario – in this case the capital cities of Australia and New Zealand, i.e. concepts 1 – 9.
- Once the bust phase concludes, the designer appears to engage a search routine based on an association with previously generated concepts – the primary search routine. In this scenario, the associative link appears to be geographic proximity, as, although the designer was not allowed access to a world map during concept generation, there is a correlation between the concept generation sequence and geographic proximity, i.e. concepts 10 – 19.
- At some stage in the concept generation process, the search routine switches to some secondary search routine. In this scenario, the secondary search routine is not based on geographic proximity, i.e. concept 20. The study does not allow the basis of the secondary search routine to be identified, but it is postulated to be either: an associative link not catalogued by this study, e.g. ethnography, topography, or personal experience; free-form ideation; ideation based on review of the generated concepts; or combinations of these search routines.
- Once the secondary search routine identifies a region not previously identified, the primary search routine identified may again become active, e.g. concepts 20 – 21.
- The designer then appears to switch between the primary and secondary search routines, in an attempt to identify new regions, and to ensure that the identified regions are fully catalogued. As this process continues, the concept generation rate diminishes, and the designer experiences a series of concept generation droughts, i.e. concepts 30 – 32. Eventually the drought threshold is exceeded and the designer terminates the concept generation process.
- In response to a gestation period, the designer is typically able to identify a number of new concepts. It appears that the secondary search routine is typically employed in this phase of concept generation, however the primary search routine may be employed if a new region is identified, e.g. concept 34 – 36. Concept generation subsequent to a gestation period is typically dominated by a series of concept droughts.
- The low level of domain-specific knowledge of the designer is indicated by the absence of responses identified in the South American continent.

The assessed case study is consistent with trends observation in concept generation tasks with less easily identified associative links, for example as occurs in response to creative problem-solving scenarios. Further assessment is required to confirm these observations.

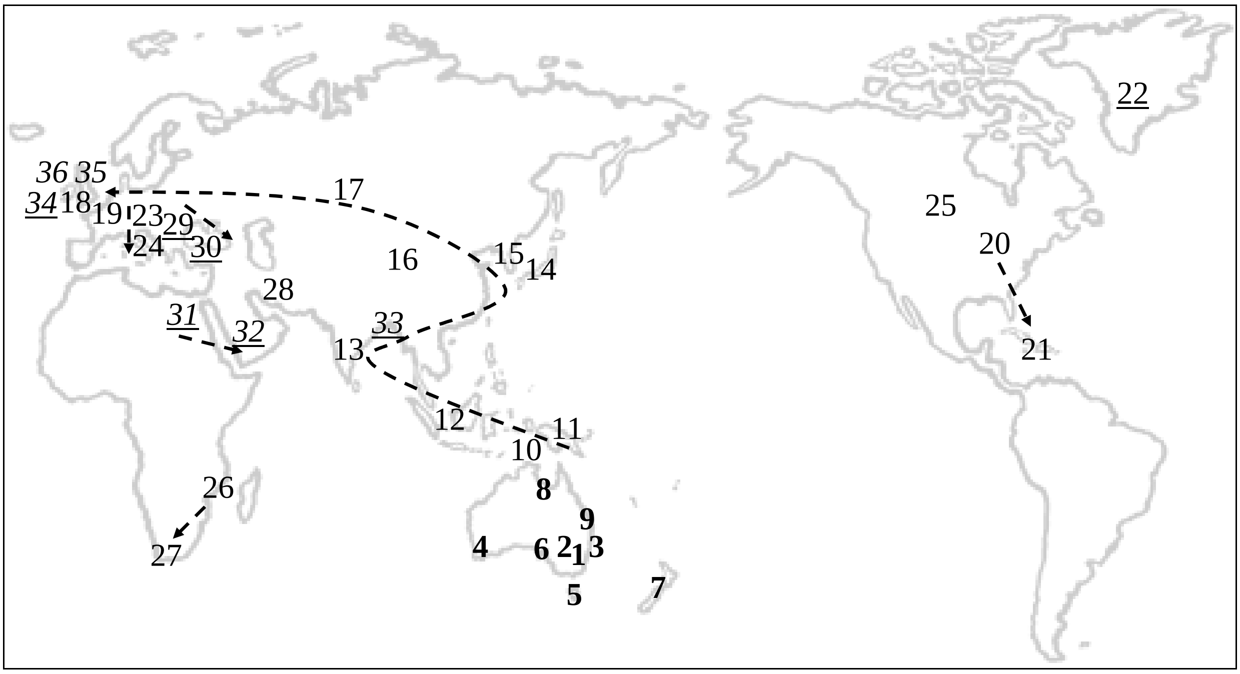

Figure 5. Plot indicating the concept generation sequence for a designer generating a list of capital cities. Bold numerals: Concepts generated during the burst phase. Normal numerals: concepts generated during the exploratory phase. Italic numerals: Concepts generated after a gestation period.
Underlined numerals: Concepts generated after a concept drought.
Arrows indicate a correlation between concept generation sequence and geography.

5 Conclusions

A novel computer based sampling tool has been developed to document the concept generation process. The sampling tool had been demonstrated as an effective means of recording the concept generation process. The sampling tool was applied to examine the concept generation outcomes in a range of general knowledge based tasks. The observed concept generation characteristics displayed two distinct phases, i.e. a linear “burst phase” and an asymptotic “exploratory phase”.

The sampling tool was applied to qualitatively assess the influence of a range of design scenario attributes on the concept generation outcomes in a series of case studies. This preliminary study has identified correlations between concept generation outcomes and several attributes of the design scenario, specifically:

- The designer will typically identify further concepts if the concept generation period is extended beyond the designers internal “drought threshold” [5]. The volume of additional concepts generated is small, but these concepts may be of a particularly innovative nature, and therefore of greater value to the design process.

- Increased domain-specific knowledge extends the duration of the burst phase and increases the response ceiling, but does not appear to significantly influence the rate of concept generation during the burst phase.

- It was universally observed that the inclusion of a gestation period increased the response-ceiling [6], even when the initial concept generation task includes an extended concept drought where no new concepts are generated.

These correlations are of particular importance to accelerated New Product Development (NPT) [9]. Specifically, that an extended concept generation time and the application of a gestation period are highly beneficial to the concept generation process and should be incorporated in accelerated NPT, regardless of the associated increase in development time.

During the exploratory phase, the designer appears to apply internal "search routines" to assist the identification of new concepts. This hypothesis was tested with a concept generation scenario, and the basis for the "primary" search routine was identified – in this scenario the primary search routine was based on geographic proximity. A "secondary" search routine was identified, but its basis could not be determined from the data available to this preliminary study.

References

[1] Samuel, A. and Weir, J., “Introduction to Engineering Design”, Butterworth Heinemann, 1999.
[2] Pahl, G. and Beitz, W., “Engineering Design. A Systems Approach”, Springer, New York, 1995.
[3] Dieter, G., “Engineering Design, a Materials and Processing Approach”, McGraw Hill, Singapore, 2000.
[4] Burvill, C., Leary, M. and Weir, J., “Responses of Novice Designers to Unstructured Problems”, 14th International Conference in Engineering Design ICED 2003, paper 1195, Stockholm, p. 255, 19-21, 2003.
[5] Busby, J. S., Lloyd, P. A. and Deasley, P. J., “Do Design Organisations Explore Too Few Solutions?”, 12th International Conference in Engineering Design ICED 1999, Techniche Universität München, Munich, Vol. 1, pp. 551-554, 1999.
[6] Blake. R.R., Mouton. J. S., “The Managerial Grid III. The Key to Leadership Excellence”, Gulf Publishing, 1978.
[7] Pache, M., Romer, A., Lindemann, U. and Hacker, W. “Sketching Behaviour and Creativity in Conceptual Engineering Design”, 13th International Conference in Engineering Design ICED2001, Glasgow, pp. 461-468, 2001.
[8] Bender, B., Martin, K. and Beitz, W., “A Model of Analysis to Improve Teamwork Performance”, 12th International Conference in Engineering Design ICED 1999, Techniche Universität München, Munich, Vol. 1, pp. 177-182, 1999.
[9] Hendriks, D. and de Wilde, H., “Project Managements for New Product Development Projects: An Empirical Study”, 12th International Conference in Engineering Design ICED 1999, Techniche Universität München, Munich, Vol. 1, pp. 555-558, 1999.
[10] McGeer, P. L., Eccles, J.C. and Edith, G. “Molecular Neurobiology of the Mammalian Brain”, Plenum Press, New York, 1978.

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