INTERNATIONAL DESIGN CONFERENCE - DESIGN 2010
Dubrovnik - Croatia, May 17 - 20, 2010.

DESIGN 2010

EMOTION ELICITATION DURING A COGNITIVE TASK

R.J. de Boer, P. Badke-Schaub and S.C. Santema

Keywords: emotion, mental models, cognitive tasks

1. Introduction

This paper presents the intermediate results of research into the role of emotions in the preservation of Mental Models when challenged by contradictory stimuli. This investigation is inspired by the practical experience of the first author in industry, where he has witnessed how seemingly rational problems within teams gave rise to all sorts of emotional responses. In this paper we will show that an in itself fully rational (i.e. unemotional) interaction will give rise to emotions when feedback is not in line with the subject's existing mental model. Furthermore, we have classified the resultant emotions and their effectiveness to preserve or maintain the mental model. We discuss these findings in relation to the functionality of mental models and emotions for engineering and design activities.

2. Theoretical exploration

2.1 Mental Models

In the science of design methodology, ideas or mental representations are a necessary concept. The activity of design can be described as ongoing translation of requirements by mental processes (using and transforming these ideas) into a final deliverable. At any point in time, an individual has a mental representation of the task objective, the task difficulty related to his own efficacy, and possible task solution strategies including their relative appropriateness [Neumann, Badke-Schaub et al. 2006]. New stimuli (external) and thinking processes (internal) add to and modify this representation, making it dynamic. A construct which has been defined by Craik (1967) already in the 40'ies is called a Mental Model. Mental Models support our daily functioning by structuring and simplifying what we perceive, allowing us to concentrate attention on what is important to us and to ignore less relevant aspects. Some authors focus on the explicit knowledge that an individual can express and is conscious of. However, Mental Models also include implicit or tacit knowledge, routines and understanding of which we are not necessarily conscious.

Despite the importance of correct mental models for a succesful design and also for the operation of complex systems, mental models can be factually incorrect or contextually inappropriate (i.e. too generic or too specific for the problem at hand). It is important to note that this can be the case even if the thinking processes themselves have been executed 'correctly', for instance because of limited exposure to facts (knowledge and reality; in the past and present), or the ability to process stimuli (perception) is hampered.

Stempfle and Badke-Schaub (2002) have defined four basic thinking processes (generation, exploration, comparison, and selection) that are necessary in design, but are probably valid for any kind of problem-solving in a complex field. In an empirical study the authors identified how each of the basic thinking operations relates to activities within the design process, covering both content and management. Results show that due to restricted or missing analysis mental models are often

incomplete and do not allow the designer to take a sound decision. However, inaccuracies in the mental model are also the result of a trade-off between the effort required to maintain an accurate representation of reality, and the cost of inappropriate behavior due to possible imprecision in the model [Boos 2007].
Because Mental Models guide our actions (including choosing the situations we are coping with and the stimuli we endure), we can expect that Mental Models will be preserved even if contradictory stimuli some are available.

2.2 Emotions

Emotions are functional expressions of action tendencies[1] that strengthen or weaken the relationship with an object or another person; whether and what action or behaviour will be chosen is subject to regulation processes. The emotion process is triggered an external event that is 'appraised' (evaluated) as important to an individual's concern. Emotions are accompanied (in general) by bodily arousal, focusing of attention (control precedence) and affect (a feeling of pain or pleasure) [Lewis 2005; Frijda 2007].
Emotions are threshold phenomena; i.e. an emotion materializes after a stimulus has been appraised as significant. The initial appraisal is subconscious, and only after passing the threshold do we become conscious of the emotion (and the triggering event), allowing cognitive processes to become involved. The emotion manifests itself primarily through focus of attention and affect, and indirectly through arousal and feedback about our tendency to act.
The affect associated with emotions directs striving: one strives to avoid negative affect and to create positive affect. Feelings thus generate support and urgency for arousal, attention and action tendency.
Action Tendencies have been described as the factor that discriminates emotions from other types of phenomena involving feelings (mood, dispositions, personality traits, etc.) [Frijda 2007]. It seems plausible that whereas the list of possible emotions is nearly of infinite length, action tendencies are limited (Frijda lists less than 30, included in Table). Most of these are readily linked to certain groups of emotions, although different emotions may share the same action tendency (as do "timidity" and "fear"), and some emotions correspond with multiple action tendencies (as "anger" implies both "oppose" and "hurt").

Table 1. Action Tendencies [from Frijda 2007]

Attend	Disappear from sight	Amend
Interest, savour	Be with	Undo
Shut off	Fuse with	Hurt
Approach	Dominate	Reactant
Withdraw	Submit	Broaden and build
Reject	Possess	Depend
Oppose	Care for	

Note that "the behavioural component of emotions is in many ways 'expressive' in nature; i.e. emotions do not in themselves communicate the state of mind, but signal a request or an intention aimed at changing the way two (or more) individuals interact" [Frijda 2007]. This implies that in classifying and understanding emotions, we need to look further than the direct impression of anger, fright, surprise etc., and analyse the situation through an understanding of the action tendencies. These then form an important analytical parameter for our research.

3. Research Design

3.1 Research Framework

Our work presupposes that Mental Models are simplified cognitive representations of reality that are functional in freeing up mental resources and/or saving energy. This implies that the integrity of the Mental Model is not reassessed at every new stimulus, but equally that genuine and significant contradictory information is not ignored. We speculate that emotions (as a part of their more general

[1] Underlined the five "A's" that define emotion.

functionality) are instrumental in preserving Mental Models, yet allowing non-trivial stimuli to be processed. This framework is captured in Figure . Two parallel processes are depicted, one purely conscious and cognitive, and a second where an emotion is triggered by a subconscious appraisal. The appraisal filters relevant from non-relevant stimuli, and the emotional process leads to awareness of the former through attention (even if the subject was previously unaware of the stimulus, i.e. the processing is subconscious). In addition, action tendency and arousal prepare the subject for action. Affect supports the decision making processes as suggested by Damasio [1996] and biases the subject for certain routes of action.

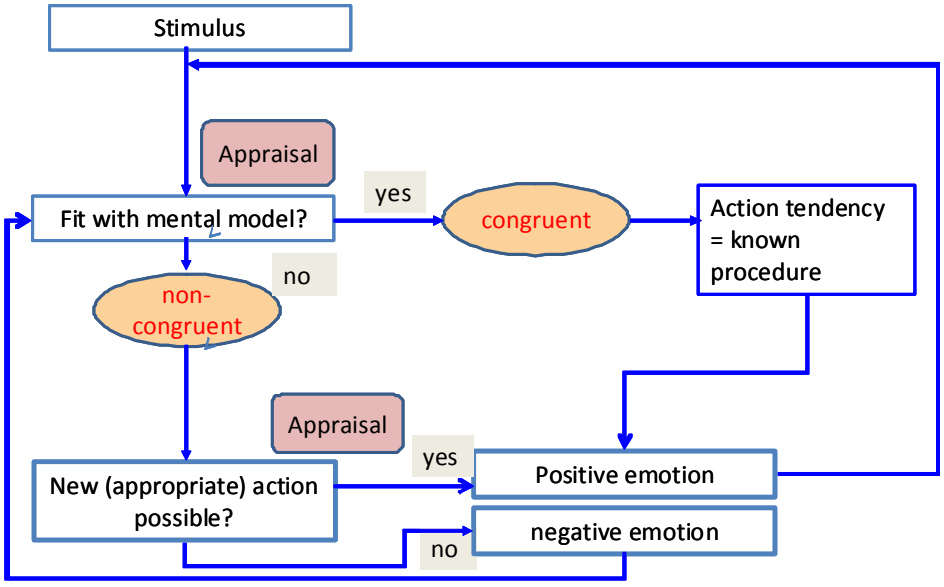

Figure 1. Framework of stimulus – response sequence

We expect that an emotion is triggered if a stimulus contradicts an established Mental Model and the stimulus is above a certain (subject dependent) threshold. The emotion will manifest itself as affect, focus of attention, action tendency (subject to regulation processes) and arousal. We hypothesize that:

- The affect will be negative in case of a challenged Mental Model, signalling a bias to avoid the situation and preserve the Mental Model.
- Immediate attention will be given to the stimulus if over the threshold; however attention may be redeployed and the stimulus ignored as a result of regulation processes; this will correlate with the preservation of the Mental Model.
- When a Mental Model is challenged the action tendency will fall broadly into two categories: rejection or opposition (associated emotions commonly called anger, irritation, frustration); or submission (generally signalled by laughter).
    - The action tendency of rejection or opposition will be correlated with a preservation of the mental model.
    - The action tendency of submission will be correlated with the demise of the Mental Model.

Changes in arousal levels seem to accompany most emotions, particularly when the action tendency mode changes radically (from rest to immediate physical action, or from effort to a state of apathy). Whether arousal changes occur in case of a challenge to the Mental Model remains to be seen, as the task will require effort in itself and the expected action tendencies may not be very physical.

3.2 Research Questions

The research questions which are to be addressed in this study are therefore:

- In what way do emotions occur with the demise of a Mental Model during a cognitive task?

- Can we identify a systematic occurrence of emotions during the generation and discard of Mental Models, and if so with which aspects of the demise of the Mental Model do the occurrence of emotions coincide?
- Can we validate the functional explanation for the occurrence of emotions during the generation and discard of ideas?

3.3 Research Approach

In order to come close to the mental model the person develops during the performance of a task it is necessary to devise a design / engineering-like task that is rather simplified to enable us to study the mental model and emotional reaction. We have chosen a "number reduction task" that includes the following characteristics of a design task:

- Search for a solution within constraints and objectives given by an external authority
- Recognition of patterns
- Creation of novel ideas
- Multiple iterations in which solutions are generated and alternatives are evaluated

Although our ultimate interest lies with teams of engineers, we need to understand these processes at an individual level first. This is the scope of the present study; the individual setting also ensures that the emotions that are generated are not the result of social interactions. In the continuation of this research the findings will be validated with design teams.

After we have been able to ascertain the establishment of a Mental Model in the execution of the task, we will present stimuli that will challenge the current mental model. Both the cognitive and emotional responses are monitored and will be correlated. The experiment has been run. The experiment will be described in chapter 4, and the findings will be presented in chapter 5.

4. Experimental Exploration

4.1 Methodology

30 engineers from industry and engineering students have been asked to perform a relatively simple but prolonged cognitive task within a limited time period. The initial solution strategy that the subject has been taught does not enable him to satisfy the time objective of 30 seconds for ten trials, with no more than one error. Therefore, he will search for an alternative strategy, test this, and conclude that he has solved the problem – thereby establishing a Mental Model. However, just as he thinks this is the case, the input parameters change – unknowing to him - so that the current mental Model is no longer valid.

The assignment is based on the Number Reduction Task originally developed by Thurstone and Thurstone in 1941. Subjects are required to 'reduce' a seven-digit string[2] into a final number by making use of two simple rules:

- The "same" rule: if the two input digits are the same, then the resulting digit is the same.
- The "different" rule: if the two input digits are different, then the result is the third, different digit.

The strings and answers only consist of three different digits: 1's, 4's, or 9's.

It is impossible to complete a set of ten strings within the given time by applying the two rules sequentially for each string. The time pressure of the task compels the subject to search for alternative strategies. Unknown to the subjects, there is a pattern in the strings that allows a short-cut from six repetitive calculations for each string to only one, if they identify a hidden pattern in the calculations. We can monitor their search for the pattern and the establishment of a Mental Model through the individual key strokes that are recorded by the software.

Note that the pattern in the strings is applicable only to those selected by the researchers. This allows us to challenge the Mental Model once it has been sufficiently fortified, by giving alternative, non-

[2] Original design using an eight-digit string proved too difficult in pre-trials.

compliant strings that do not adhere to the pattern. This forms the foundation of our experimental condition, whereby the established Mental Model is challenged by contradictory stimuli.

4.2 Participants

Subjects were recruited from the Delft University of Technology as well as from industry. All subjects had an educational level sufficient to be accepted at a Dutch academic institution. The characteristics of the subjects are summarized in Table .

Table 2. Summary of subject data

Gender	Age	Education	Discipline	Profession
4 Female	20 Min age	3 Doctorate (PhD)	23 Aerospace Eng.	15 Full-time student
26 Male	62 Max age	8 Masters (WO)	3 Design Eng.	8 Engineering
	17 20-29	7 Doing a MSc deg.	2 Other sciences	1 Other
	9 30-49	4 Bachelor (HBO)	2 Other	2 Technical Mgt.
	4 50+	8 Doing a B degree		4 Consultancy

4.3 Measures

4.3.1 Mental Model

The software registers all subject responses (exact numbers, use of tab, correctness and the duration of the response), as well as the input stimuli (exact numbers, compliance with pattern). Separately, the subject is asked about his confidence in fulfilling the task after every set (5-point Likert scale, very unconfident – very confident) and this is captured on a registration form and on video.

The establishment of the mental model is defined as having recognized the pattern and automated the response to each string. It is operationalized by the use of the tab key and a duration per response of less than four seconds (based on pre-trials). Demise of the Mental model is characterized by a response duration longer than 8 seconds, as defined by the minimum time required for a stepwise calculation[3].

4.3.2 Emotion

Emotions are registered through three means: Heart Rate measurements, self-report and video observation. Each of these are discussed in the paragraphs below.

The physiological reaction of the subjects is monitored by a commercially available wireless heart rate receiver/transmitter worn on a belt around the chest. In the analysis the Heart Rate has been normalized for subject to subject variation according to the following formula:

$$HR_{t,normalized} = \frac{HR_t - \overline{HR}_{rest}}{\sigma_{rest}} \quad (1)$$

where rest denotes a pre-trial 10 minute period in which the subject performed a computer task with limited emotional stimuli.

[3] This threshold follows from pre-trials. Use of the tab key is not discriminatory at this stage.

For the self-report, subjects have been asked to report their feeling both in words and by numbers in a range of +5 (very pleasant) to -5 (very unpleasant)[4]. The self-report is registered on video as well as on a form.
A video registration is available for the duration of the total experiment for each subject. The emotions have been categorized using a description of the facial expression and verbalization. We have based our classification on a limited number of the action readiness categories described earlier. These are summarized together with the expressive behaviour in Table 3.

Table 3. Classification of emotions

Stimulus	Emotion	Action Tendency	Visible behaviour
As expected	None	None	None
Contradictory	None	None	None
	Surprise	Attend to new circumstances	Focus attention, analyze new information
	Anger, frustration	Reject, oppose, shut off new circumstances	Frown, grimace, shake head, shrug
	Relief	Submit to new circumstances	Laughter, smile

4.4 Procedure

The results reported here are based on experiments from April to October 2009 (the study is continuing at present). The subject is first briefed about the experiment and signs the consent form. He puts on a Heart Rate monitor. Video registration is started. A personality test is first administered[5], and serves as a baseline for the Heart Rate measurements. Then the software to administer the Number Reduction Task is started. The software presents a screen with the text "You are now ready to start the test", after which the first set of strings is presented to the subject. After each set of ten strings the subject is given feedback on his performance, and is asked to record his confidence in fulfilling the task, his feelings and his intentions on the registration form. He is asked to answer the same into the camera. This continues until the subject has been able to twice fulfil the task objectives (a set of ten strings within 30 seconds and with one error or less). At that point, the software will include at random strings that do not comply with the pattern, with an average of three per set. The software will continue to offer sets until the objective has been fulfilled three times or 130 sets have been offered. But in general the test supervisor concludes the experiment after a full hour. The subject is debriefed about the intentions and the test manipulation, and in case of students a payment against an invoice is made.

4.5 Manipulation check

To study the demise of the Mental Model, we first need to ascertain whether the Mental Model has been properly established. Figure shows a typical example of the progress of the test. The continuous line represents the duration of the response for each input string. The blocks (when unequal to zero) indicate an error in the response.
Clearly visible are three phases for the Mental Model:

- "Learned Model", where the rules that have been learned are applied as instructed. This leads to an exponentially decreasing duration per string that however does not allow the subject to

[4] For the first few subjects only a verbal description of the feeling was requested.
[5] The results of the personality test will be correlated with the current experiment in due course.

fulfil the objective of about 3 seconds per string (equal to 30 seconds per set of ten strings). Initially there may be some errors as the rules are not quite internalized.

- "Pattern Model", where the subject has recognized the pattern and is able to respond in less than 4 seconds without errors.
- The challenge to the Mental Model is realised by input strings which do not comply with the pattern. Errors are made (at least on the non-compliant strings) and response times increase and become more erratic.

The phases are interspersed by periods with highly erratic response times and occasional errors where the subject is searching for a successful alternative strategy. Additional cues not shown in the graph (notably use of the tab keys and verbal responses) were used to ascertain the successful manipulation.

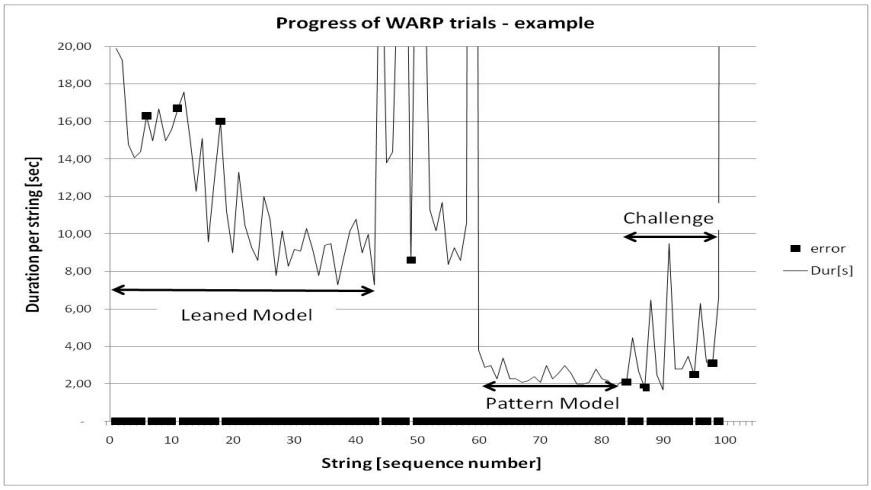

Figure 2. Typical progress of the test

The continuous line represents the duration of the response for each input string. The blocks (when unequal to zero) indicate an error in the response. Clearly visible are the three phases of the Mental Model

In Figure 3 the continuous line represents the response duration for each string for a subject whose Mental Model is not refuted (the duration remains under eight seconds). The dashed line shows the response by a subject who is contemplating his strategy after two errors (shown as triangles). Eventually he manages to answer correctly to non-compliant strings (shown as circles at string 16, 17 and 27). Note that only for non-compliant strings the correctness of the response is indicated.

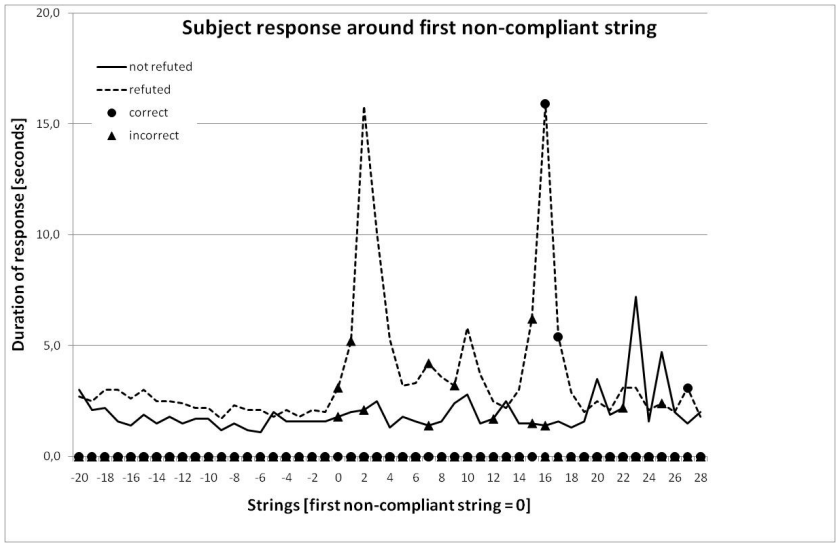

Figure 3. Comparison of responses at Mental Model challenge between two subjects

In most but not all cases the manipulations were successful in establishing a Mental Model about the hidden pattern and then challenging and refuting it. The manipulation was not successful for 12 subjects; these either preserved the Learned Model (despite its conflict with the task objectives) or did not establish the Pattern Model[6]. The remaining 18 subjects established a Mental Model of the pattern in sufficient robustness to be able to complete two sets of ten strings within 30 seconds with no more than one error. The number of strings required to achieve this varied from 4 to 17 sets (with an average of 10) and 8 to 36 minutes net test time with an average of 24 minutes. All trials continued for at least another two full sets from this point onwards to enable sufficient challenge to the Mental Model.

5. Results

5.1 Demise of the Mental Model

In four cases the Mental Model was not successfully challenged, and the subject continued to apply the Pattern Model. This can be concluded from the time taken for each string, the use of the tab key, and verbal responses. The Mental Model was preserved despite the multiple errors that inhibited fulfilling the task objective. In one case the subject noticed the visual deviation of the input string and responded with a (correct) manual entry before the first error message. In the remaining thirteen cases the Mental Model was refuted and an alternative strategy contemplated after one to eight error messages per subject. The results are summarized in Table 4. In Figure two example responses are given, for a subject that preserves the Mental Model and another whose Mental Model is refuted.

5.2 Emotional response

5.2.1 Self-report

The self-report shows a reduction of the positive feeling (i.e. affect) across most subjects when the Mental Model was challenged. After the non-compliant strings were presented, the affect fell by more than a point on average (on a scale from 5 to -5). Over three consecutive sets with contradictory stimuli, the affect fell by more than two points. Four subjects did not report a drop in feeling while challenged; no subject reported an increase in affect. The results are included in Table 4. Those subjects responding in words rather than in numbers ("na" in Table 4) all reported less pleasant feelings.

Table 4. Number of error messages before demise of the Mental Model, change in affect, action tendency

Subject nr.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Number of errors	0	1	1	1	2	2	2	3	3	4	5	5	6	8	-	-	-	-
Change in affect[7]	-5	0	na	-4	na	-6	na	-1	-2	-3	0	na	0	na	na	-4	na	0
Action tendencies:																		
Attend: focus attention (a)		1			1				1	1						1	1	
Submit (to): laughing, smiling (b)	1			1		2	1	1	1	1	1	2	1	1	1	2		
Reject, oppose: frown, grimace, shake head (c)							1			1	1		2	6		2	1	3

[6] These cases will be investigated in the next step of this research project.

[7] Based on self-report over three consecutive sets with contradictory stimuli; some na (not available) because initially the question was not phrased numerically, see footnote 4, these all reported more negative affect.

Shut off: shrug (d)								1				2	1	1				2
No visible reaction (e)			1		1			1	1	1	3	1	2		4	3	6	2
First reaction	b	a	e	b	e	b	c	d	e	a	e	c	c	c	e	b	c	c
Reaction pre-demise	b	a	a	b	a	b	b	e	c	e	e	d	d	c	-	-	-	-

5.2.2 Video observation

The video observation has been analyzed to determine the reaction of the subject in terms of emotional behaviour. The number of times that each subject demonstrated the action tendency immediately following an error message is included in Table 4, as well as the reaction to the first (most unexpected) error message. As can be seen, every subject showed a reaction to some error messages, although not necessarily for every error. The action tendencies after the first error message and just before demise of the Mental Model vary from subject to subject.

5.2.3 Heart Rate measurements

The Heart Rate measurements have as yet not generated a useful signal of emotions. The average normalized Heart Rate calculated over all[8] subjects drops more than one point around the first non-compliant string. However, this drop is not significant in comparison with the standard deviation of the normalized Heart Rate of about 1,9. The effect of arousal from emotions seems to be confounded by changes in effort: averaged over all sets and subjects, the normalized Heart Rate increases by 0,5 during the course of each set, to drop again during the feedback session at the end of each set.

6. Discussion

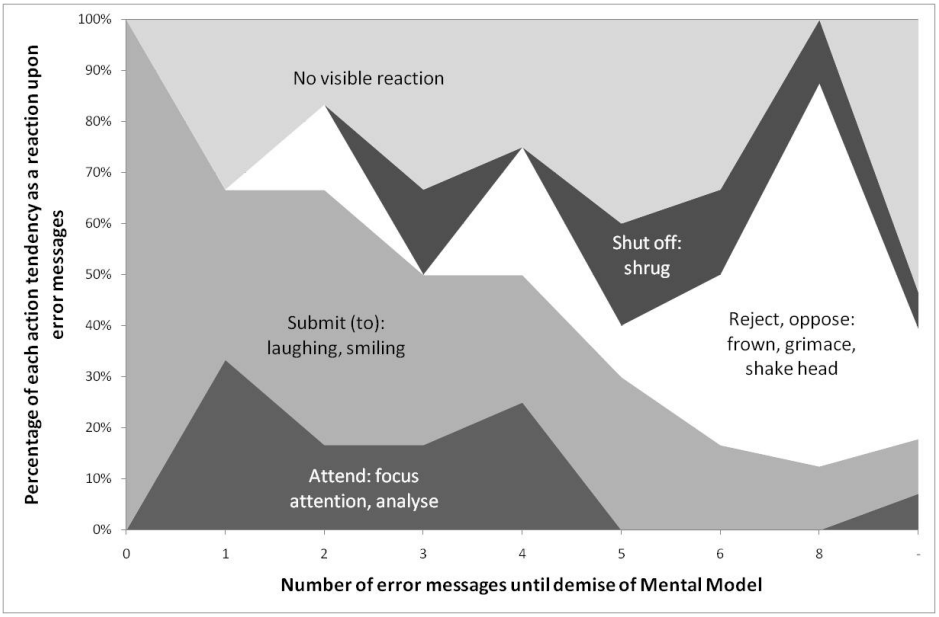

Figure 4. Action tendencies as a function of Mental Model demise

In all cases of challenge of the Mental Model we were able to determine an emotional reaction, in most cases as a less pleasant (self-reported) feeling, and in all cases through action tendencies. Even where no change in affect followed from the self-report (except in subject 2), the action tendencies included rejection or opposition to the stimuli, signalling a bias to preserve the Mental Model.

[8] For two subjects the HR measurements failed.

In all but two cases the action tendencies on error messages included the two categories mentioned in chapter 3.1: rejection or opposition (commonly called anger, irritation, frustration); or submission (generally signalled by laughter). As expected, the action tendency of rejection or opposition was relatively more frequent in a slow demise of the Mental Model. The action tendency of submission correlated with the faster demise of the Mental Model.
This is illustrated in figure 3, which shows the number of error messages until demise of the Mental Model on the horizontal axis. The relative frequency of the action tendencies is shown on the vertical axis. There where demise is relative quick (to the left side of the graph) the responses of submission were more numerous. To the right, rejection of opposition is more pronounced. As expected, not all error messages gave rise to an emotion. For some subjects the initial error message was disregarded, in other cases the error messages further along were ignored. We were not quite able to prove our expectation that the error messages that were ignored would increase with the longer preservation of the Mental Model. Particularly the single subject with eight error messages until demise did not fit the prediction.

7. Conclusion

We have shown that the demise of Mental Models correlates with an emotional reaction that seems functional in preserving the Mental Model. This fits our framework that suggests stimuli above some threshold are required to modify Mental Models. Emotional appraisal seems instrumental in assessing whether stimuli are relevant and the emotional response generates the right circumstances in terms of affect, attention, action readiness and possibly arousal to take corrective action. What action is taken is dependent upon cognitive processes which set in after the stimulus has passed the threshold and emotion kicks-in. As the stimuli are repeated, they retain their ability to trigger emotions.

Acknowledgements

We are grateful to the companies that have made it possible for their employees to participate in this study: ADSE, Fokker Aerostructures.

References

Boos, M., "Optimal sharedness of mental models for effective group performance", CoDesign, 3(1), 2007, 21-28.

Craik, K. J. W., "The nature of explanation", Cambridge University Press, 1967.

Damasio, A. R. and S. Sutherland, "Descartes' error: Emotion, reason, and the human brain", Papermac London, 1996.

Frijda, N.H.,"The Laws of Emotion", Lawrence Erlbaum Associates, Inc., Mahwah, NJ, 2007.

Grandjean, D. and Scherer, K.R.,"Unpacking the Cognitive Architecture of Emotion Processes", Emotion, 2008, 8(3), 341–335.

Lewis, M.D.,"Bridging emotion theory and neurobiology through dynamic systems modeling", Behavioral and Brain Sciences, 28, 2005, 169 - 245.

Neumann, A., Badke-Schaub, P. and Lauche, K.,"Measuring shared mental models in design teams", Proceedings of the 9th International Design Conference - DESIGN 2006, D. Marjanovic (Ed.), FMENA, Zagreb, 2006, pp. 1491–1498.

Stempfle, J. and Badke-Schaub, P.,"Thinking in design teams - an analysis of team communication", Design Studies, 23(5), 2002, 473-496.

Ir. Robert J. de Boer
PhD candidate
Delft University of Technology, Industrial Design Engineering, Dept. of Product Innovation Management
Landbergstraat 15, 2628CE Delft
Telephone: + 31 6200 17882
Email: r.j.deboer@tudelft.nl
URL: http://www.tudelft.nl