# The development of a design behaviour questionnaire for multidisciplinary teams

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*The relationship between design behaviours and successful design task completion is studied for multidisciplinary design teams. In this research, no observational methods such as audio–visual recordings or ethnographic fieldwork were used, as often the case in design research, but a questionnaire tapping critical behaviours was developed and statistically validated in two separate studies. In addition, this study presents a comprehensive view on the behaviour of design team members. The resulting* Design Behaviour Questionnaire for Teams *consists of 55 items divided into three main categories ('design creation', 'design planning', and 'design cooperation') and 12 scales.*


*Keywords: design behaviour, teamwork, questionnaire, engineering design*

Multidisciplinary design teams, in which specialised designers combine their knowledge, skills, and effort to come up with designs for high-tech products (King and Anderson, 1990; Carroll, 2000; Valkenburg, 2000), form an interesting subject of study. Successfully completing a design task within a multidisciplinary design team is an intricate matter given the complex force field in which it has to be completed (see e.g., Dorst, 2003), how straightforward as combining of resources in a team may sound. Tight deadlines, high technological standards, teams consisting of self-willed designers (Hales, 1993; Cross and Clayburn-Cross, 1996; Dorst, 2003), and problems arising during interaction between designers with different knowledge (Busby, 2001) are all potential threats to the effectiveness of multidisciplinary design teams in terms of design processes. To gain insight into behavioural aspects of design processes, a number of them have been studied so far: communication (Eckert and Stacey, 2001; Stempfle and Badke-Schaub, 2002), negotiation (Stumpf and McDonnell, 2002), reflection (Valkenburg, 2000), and social processes (Cross and Clayburn-Cross, 1996). Each of these behavioural aspects was studied separately, but clearly they are not independent. The force field in which designing takes place not only owes its

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complexity to those many behavioural aspects, but even more so to their intertwinedness. In order to do justice to this complexity, studies into behavioural aspects contributing to design team effectiveness should take a more integrative approach, which is also noted by some of the researchers mentioned above. Our aim in this study is to use such an integrative approach in order to develop an instrument to measure those behavioural aspects, the *Design Behaviour Questionnaire for Teams* (DBQT). With the DBQT, behaviour directed at successful design task completion within multidisciplinary design teams can be measured. It is aimed to provide a generic reflection of the behavioural aspects of the design process that support or hinder successful design task completion as fully as possible.

We approached the development of the DBQT by analysing the task of multidisciplinary design team members. Using task analysis, researchers and practitioners (e.g., HRM) aim to provide a complete description of behaviours critical for successful completion of a specific job, function, or task. To our knowledge, designing in multidisciplinary teams has not been subjected to a task analysis before. Doing so may not only aid in establishing the criticality of the behavioural aspects with regard to successful design task completion, it may also turn out to be a worthwhile procedure for integrating separate behavioural aspects of the design process of multidisciplinary design teams that were objects of study so far.

The question we research is: *What specific design team member behaviours are critical in order to establish favourable dynamics during designing, thereby resulting in successful completion of the design task of multidisciplinary design teams?* We focus on *behaviours* (cf. Günther and Erhlenspiel, 1999), because behaviour is an *observable* design process characteristic that can be discussed or affected in order to manage effectiveness. Naturally, for effectiveness only *critical* behaviours are of interest. In addition, we focus on *specific* behaviours, since the more specific behaviours are described, the more information they provide for actions to be taken. By focusing on observable behaviour, we are not saying that cognitive processes are not critical for designing (see, for example, Cross, 1990, 1999). However, cognitive processes are difficult to observe and therefore less accessible to direct interventions.

Designers are central to this study, because we consider them to possess expert knowledge on (a) the behaviour they display during the course of the design process, and (b) how in their experience this behaviour relates to successful design task completion. We draw upon this rich source of designers' expert knowledge for our task analysis. The behaviour of designers who collaborate within multidisciplinary teams has been the object of study before. Up till now, design team member behaviour has been studied in protocol studies in both lab (e.g., Cross et al., 1996) and field settings (e.g., Badke-Schaub and

Frankenberger, 2002), in ethnographic (field) studies (e.g., Bucciarelli, 1988; Baird et al., 2000; Eckert and Stacey, 2001), in case studies (e.g., Peng, 1994; Sonnenwald, 1996), and in interviews (e.g., Denton, 1997; Tomes et al., 1998; Reid et al., 2000; Lawson, 2004). As stated before, the majority of these studies have focussed in depth only on a single behavioural aspect of the design process. By making exhaustive use of the knowledge of designers, we are able to look at designing in multidisciplinary teams with a broader view. In addition, by measuring behaviour of design team members by means of questionnaires, theories on behavioural categories and on relationships between such categories and design team outcome variables can be put to statistical test, which cannot so easily be done when the above mentioned data gathering techniques are used.

In order to convert designers' knowledge into a valid and reliable questionnaire, a particular method is required. The construction of the instrument has been done in two steps, which are subsequently described in study 1 'Analysing the task of designing in multidisciplinary teams', and in study 2 'Constructing the Design Behaviour Questionnaire for Teams'.

# 1 Study 1: Analysing the task of designing in multidisciplinary teams

## 1.1 Method

To perform our task analysis of designing in multidisciplinary teams, we used the Critical Incident Technique (CIT) (Flanagan, 1954). The CIT 'consists of a set of procedures for collecting direct observations of human behaviour in such a way as to facilitate their potential usefulness in solving practical problems and developing broad psychological principles' (p. 327). Flanagan defines an incident as 'any observable human activity that is sufficiently complete in itself to permit inferences and predictions to be made about the person performing the act' (p. 327). Furthermore, he states that critical incidents that are collected should have 'special significance' and should meet 'systematically defined criteria'. Over the years the CIT has proven its worth: entering 'critical incident technique' in the PsycInfo database provides well over 200 hits of studies in which the CIT has been used. Given its definition, this technique is very useful for our purposes, since we aim to solve the practical problem of developing an instrument that maps critical behaviour displayed by designers during design work in multidisciplinary teams. To construct a data pool of critical behaviours of design team members, we followed the five steps of the CIT (Flanagan, 1954). Here we only briefly summarise these steps. For a more detailed discourse on each of them, we refer to Flanagan (1954, pp. 336–346); for a detailed description of how we applied these steps in our study, we refer to Peeters (2006). An overview of the steps performed in study 1 can be found in Figure 1.

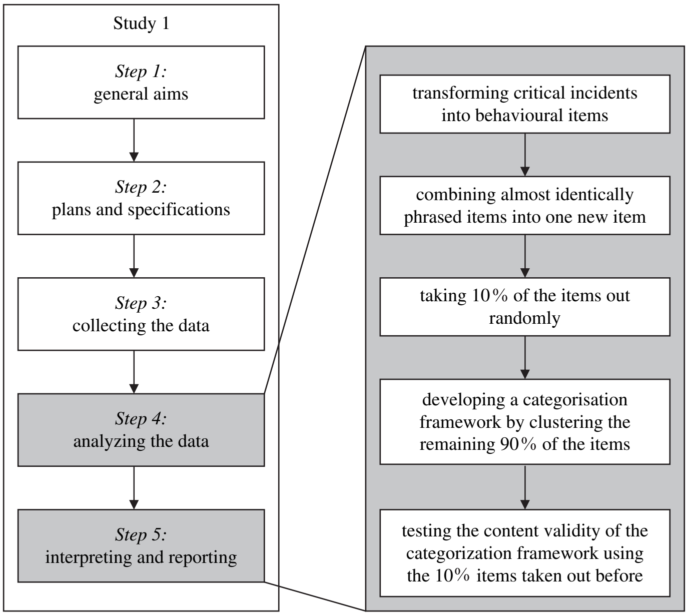


*Figure 1 Overview of the steps in study 1. The development of the categorised data pool on critical design behaviour in multidisciplinary teams*

In step 1 'General aims', the goal of designing in a multidisciplinary team was described. The goal of this activity is successfully completing the design task.

In step 2 'Plans and specifications', we defined what situations are of interest and what persons are to be interviewed on these situations. Candidates for the interviews were selected out of the alumni database of the institute that provides eight 2-year post-master's design programmes leading to a Professional Doctorate in Engineering (PdEng) at the Technische Universiteit Eindhoven.

In step 3 'Collecting the data', the interviews were conducted. The main part of these interviews concerned questions about the critical incidents. The interviewees were asked the following questions: 'How do team members contribute to the degree to which the design project is successful? Can you give me concrete examples (preferably not older than six months) of behaviour of team members that were critical for the success or failure of the design project? Would you describe per example: (1) What the situation was like (*antecedent*), (2) What the team members did in the given situation (*behaviour*), and (3) What the effect of their behaviour was (*consequence*)'. The answers to these three questions together formed a critical incident. The interviewees were asked to come up with as many critical incidents as possible.

Step 4 'Analysing the data' and step 5 'Interpreting and reporting' were performed following the detailed prescriptions for those steps offered by Latham and Wexley (1994, pp. 56–61). In short, the main steps include transforming critical incidents into behavioural items, combining almost identically phrased items into one new item, taking 10% of the items out randomly, developing a categorisation framework by clustering the remaining 90% of the behavioural items, and finally testing the content validity of the categorisation framework by testing whether the 10% left out items fit into the framework. Content validity is concerned with the degree to which items included in a category or rating scale are a representative sample of all important items that could have been included in the category or scale. The above steps are displayed in the grey box in Figure 1. Elaborate descriptions can be found in Peeters (2006).

## 1.2 Results

We conducted interviews with 13 interviewees from seven technological companies in the southeast of the Netherlands (step 2). Five of the interviewees were project leaders, eight were designer or process engineers. Eight of the interviewees qualified the designs of their team(s) as innovative, four as incremental and one as a combination of both. The branches their teams operated in were architecture, chemical engineering, industrial design, information and communication technology, mechanical engineering, and mechatronics.

In total 120 critical incidents (in each of which antecedent, behaviour, and consequence were described) were reported by the interviewees (step 3); the majority of the interviewees reported between eight and 12 critical incidents, with one exception of 15 reported incidents (average = 10). This indicates that the responses were evenly spread over the respondents and none of them was overrepresented. From these 120 critical incidents 299 behavioural items regarding team member behaviour were extracted. An example of behavioural items extracted from a critical incident is given in Table 1. From the behavioural items seven were similar to other items, which reduced the total number to 292 behavioural items.

After taking out 10% of the items, the remaining behavioural items were first used to establish a categorisation framework. Three raters independently developed categories by clustering items which in their opinion were related to another in terms of content. Comparing the resulting categories lead to the conclusion that these categories mainly differed in terms of level of aggregation. A hierarchical structure of main categories and subcategories within each main category could easily be detected. The three main categories were 'design creation', 'design planning', and 'design cooperation'. The first main category contained items on the actual creation of the design and encompasses subcategories like establishing the design goal, elaborating the design, and reflecting on the design. The second main category contained items that concerned issues with respect to dealing with time during the design process such as planning time, keeping schedule and evaluating the schedule, efficient use of time, or meeting responsibilities timely. The third main category contained items on social processes going on between the design team members,

**Table 1 Examples of behavioural items extracted from a critical incident**

| Interview 2, Critical incident 4 | | |
|---|---|---|
| Antecedent | Behaviour | Consequence |
| During the project a severe problem occurs which might seriously slow down the project. | A plan is made to counter the problem. | The designer who signalled the problem feels taken seriously. |
| | A deadline is set for solving the problem. | The problem is solved within planned time. |
| | Capacity is set free by momentarily putting all other things aside to execute the emergency plan. | |
| | ↓ | |
| | *Behavioural item*<br>27. Resources are redistributed according to newly arising priorities.<br>59. Design team members accommodate their work schedule in order to solve problems suddenly arising during the course of the project. | |

like making arrangements about cooperation within the team, and on evaluating the cooperation between the design team members and their external environment, like communication and documenting decisions. The final framework met all criteria formulated by Flanagan (1954, p. 345). All main and subcategories of the categorisation framework are presented in Table 2.

Next, each of the raters categorised all 292 behavioural items within the framework. They agreed upon the categorisation of 187 of the 266 behavioural items used to develop the framework. This resulted in an interrater reliability of 0.70. After discussion and recategorisation of the items that had been disagreed upon, agreement was reached upon the categorisation of 243 behavioural items, resulting in an interrater reliability of 0.92, which was satisfactory to continue. A categorisation system is reliable if it yields the same data regardless of when the items are categorised and by whom the categorisation is done. Interrater reliability refers to the agreement (consistency) between two or more independent raters (Cooper and Schindler, 2003).

Thereafter, content validity was checked. A fourth independent rater categorised the 10% of the behavioural items that had been left out initially. All items could be subsumed under one of the categories of the framework developed by the three raters and only one item was categorised differently. So, categorisation by the fourth rater did not require the addition of a new category, neither did it result in the addition of two or more new behavioural items to an existing category. This allowed for the conclusion that the content validity of the

**Table 2 Category framework for design behaviour scales for teams**

| Main category | Subcategory |
| --- | --- |
| *Design creation* | Establishing the design goal |
| | Gathering information, generating ideas and solutions |
| | Restricting/combining solutions, establishing the concept |
| | Elaborating the design |
| | Phase transition |
| | Reflecting on the design |
| | Adjusting based on reflection |
| *Design planning* | Planning time |
| | Establishing responsibilities per discipline |
| | Keeping schedule |
| | Evaluating the schedule, use of time, or meeting of responsibilities |
| | Adjusting the schedule, use of time, or responsibilities based on evaluation |
| *Design cooperation* | Making arrangements about the cooperation within the team |
| | Cooperation |
| | Evaluating the cooperation |
| | Adjusting the cooperation based on evaluation |
| | Communication |
| | Making decisions |
| | Documenting decisions |

subcategories of the categorisation framework was ensured. In the final data pool we included only items that had been agreed upon by all three raters. So, this final data pool consists of 243 items, subsumed under the 19 subcategories presented in Table 2.[1]

# 2 *Study 2: Constructing the design behaviour questionnaire for teams*

In study 2, we provide an elaborate example of how the data pool obtained in study 1 can be used for further instrument development. We added a 5-point rating scale to a selection from the data pool items and used ratings by the members of multidisciplinary student design teams in order to statistically test the structure of the categorisation framework, in particular the structure of each one of its three main categories. In addition, several psychometrical qualities of those subcategories were investigated, such as their reliability (stability and internal consistency), and predictive validity (Cooper and Schindler, 2003). Stability is concerned with the degree to which a measurement scale is consistent or reliable over time; it does so by correlating scores gathered with the scale on two different occasions. Another measure of a scale's reliability is its internal consistency which provides an indication of the homogeneity or 'sameness' of the items of that scale. Predictive validity reflects the success of one measure in predicting respondents' scores on other measures. As a result of these analyses, the *Design Behaviour Questionnaire for Teams* (DBQT) can be presented. An overview of the steps performed in study 2 can be found in Figure 2. More details are provided in Section 2.1.

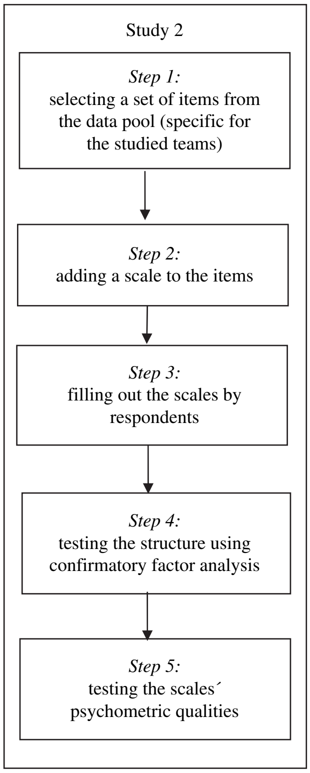


*Figure 2 Overview of steps in study 2. The development of the* Design Behaviour Questionnaire for Teams

## 2.1 Method

Data for this study were obtained from self-managing student design teams who competed in design contests that were held at each of the three universities of technology in the Netherlands in the autumn of 2003. A description of these contests is given in Peeters (2006). All competing teams had to design and build from scratch a robot that had to perform a specific task (which differed per university). In total 33 teams competed in the contests ($N = 158$) and on 25 of these teams sufficiently complete data were collected ($n = 100-106$). The teams were multidisciplinary, ranging from two to up to four disciplinary backgrounds and the average team size was 5.2 members. Of the respondents 85% was male and 15% female.

The selection of teams that were studied had implications for the part of the data pool that could be tested. All items regarding behaviour relating to interaction with a client (dispersed over the design creation and design planning categories) had to be left out, since there were no actual clients with whom teams had to interact in these design projects. The number of items that remained after taking out these questions was rather large. Since this might be expected to influence the response negatively, we wanted the questionnaire to be as tapered as possible and took two additional steps to trim it. First, scales were condensed by combining items into one item if their content allowed us to do so (for an example, see Table 3). Second, scales were inspected for their relevance for this selection of teams by asking experienced course leaders ($n = 8$) of the robot design contest to judge the applicability of each of the subcategories to the teams in their course. The questionnaire that was presented to the student designers contained 12 data pool subcategories (seven from the first main category, two from the second, and three from the third one) with a total of 85 items. Each of the items was formulated as a statement that applied to the team. For each statement, we asked respondents to indicate to what extent they agreed with it, which they could indicate on a 5-point Likert scale (1 = *highly disagree*, 5 = *highly agree*). Given the fact that project teams go through different phases in which behaviour may be displayed differently (Gersick, 1988; King and Anderson, 1990), the questionnaire was filled out twice during the design period; the first time during the project's concept phase and the second time during its elaboration phase. Testing the resulting questionnaire proceeded along guidelines described by Latham and Wexley (1994). We tested the hypothesis that the structure of the categorisation framework was correct, meaning that items categorised by the raters in study 1 as belonging to a particular subcategory would statistically form a distinct category too. This hypothesis was tested by performing confirmatory factor analysis (Stevens, 1996), separately on the items of each one of the three main categories 'design creation', 'design planning', and 'design cooperation'. Factor analysis is a technique with the objective of reducing many variables with overlapping measurement characteristics to a manageable number of (underlying) factors (Cooper and Schindler, 2003). In case of confirmatory factor analysis the technique confirms (or rejects) the hypothesis that there is a specific number of factors to which the larger number of variables can be reduced (for more details see Peeters, 2006). In addition, for the items of each subcategory, together making up a measurement scale for that subcategory, tests were performed to establish these scales' reliability (internal consistency and stability) and predictive validity. Internal consistency was established by calculating Cronbach's $\alpha$ (which measures internal consistency by correlating the odd- and even-numbered items on a scale). Stability by correlating the data gathered on the scales at two different points in time. Predictive validity by correlating

**Table 3 Example of reducing the number of scale items**

| Item | Original phrasing of behavioural item | Resulting behavioural item |
|---|---|---|
| 59 | Design team members accommodate their work schedule in order to solve problems suddenly arising during the course of the project | |
| 136 | Designers accommodate to unexpected circumstances | Design team members dealt flexibly with unexpected circumstances during the course of the project |
| 142 | Design team members adapt flexibly to unexpected events during the elaboration phase of the design project | |

the measurement scales with team outcome variables. As team outcome variables we used team member evaluations of three design aspects (design originality, technical realisation of the design, conceptual foundation of the design), as well as team members' satisfaction with three aspects of their teamwork (team method of working, quality of the team's design, the team itself).

## 2.2 Results

The results of the factor analyses are presented in Tables 4–6. For each item, tables provide the item's data pool subcategory label, the item's content, and the item's loading on the factor it distinctively belongs to. Factor loadings are the correlations between variables and factors. For each DBQT measurement scale, Table 7 provides the scale's data pool category and subcategory label, its DBQT scale label, its Cronbach $\alpha$ at both points of measurement (indicating scale reliability), and its stability score. Hereafter, we discuss separately the results of each of the factor analyses conducted on the items of the main categories 'design creation', 'design planning' and 'design cooperation'.

On the 37 items of the seven subcategories from the first main category 'design creation', a seven-factor confirmatory factor analysis was performed ($n = 104$). Items that met the specified criteria (a factor loading of 0.40 or larger on one factor only) are listed in Table 4 ($n_{\text{items}} = 24$). Seven factors fitted the data structure well, together explaining 59.67% of the variance in 'design creation'. The items on factor 1 stem from two data pool subcategories, namely 'elaboration' and 'information'. Closer inspection of item content reveals that all items pertain to collecting information or making use thereof when elaborating the design, so the scale was relabelled 'information-based designing'. The items on factors 2 and 6 all stem from the data pool subcategory 'solutions'. Inspection of item content showed that factor 2 pertains to 'confining the solution space', and factor 6 to 'building the solution space'. These factors were relabelled accordingly, in order to reflect this refinement. The items of factor 4 all stem from the data pool subcategory 'phase transition'. Although the third item in this scale lowered the scale's $\alpha$ in the concept phase from 0.87 to 0.82, we decided to retain this item in the scale for three reasons: (a) the scale's $\alpha$ can be qualified as very good with or without the item in it, (b) deleting this item makes the phase transition scale incomplete, and (c) a scale of only two items would remain after deleting this item, which is undesirable. Finally, factor 7 contained items that related to the organisation of the design task *after* the design goal had been established. The subcategory 'establishing the design goal' was therefore relabelled 'design task organisation'. The other factors in this analysis were in line with what was expected based upon the data pool categorisation, although some items had to be deleted from the scales because they did not meet the statistical criteria mentioned above. As can be seen in Table 7, with exception of the 'design goals' scale, all consistency measures were well above satisfactory levels.

**Table 4 Factor loadings for design creation items ($n = 104$)**

| Data pool subcategory label | Item | Factor | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Information | Used all available information | 0.71 | | | | | | |
| Elaboration | Developed design thoroughly | 0.54 | | | | | | |
| Information | Gathered all relevant information | 0.49 | | | | | | |
| Elaboration | Gathered necessary additional external information | 0.48 | | | | | | |
| Elaboration | Kept overall design in mind during elaboration | 0.43 | | | | | | |
| Solutions | Experimented with new solutions | | −0.56 | | | | | |
| Solutions | Restricted number of solutions | | −0.43 | | | | | |
| Adjusting | Went flexibly with unexpected circumstances within project | | | −0.76 | | | | |
| Adjusting | Adjusted sub designs to overall design | | | −0.74 | | | | |
| Adjusting | Adjusted our activities to each other | | | −0.67 | | | | |
| Adjusting | Considered overall design decisions when adjusting sub designs | | | −0.67 | | | | |
| Phase transition | Conscious transition determining concept − elaborating design | | | | −0.83 | | | |
| Phase transition | Conscious transition generating solutions − determining concept | | | | −0.79 | | | |
| Phase transition | Conscious transition setting goals − generating solutions[a] | | | | −0.45 | | | |
| Reflecting | Constantly deliberated connection between sub designs | | | | | 0.62 | | |
| Reflecting | Signalled and reported inconsistencies between sub designs | | | | | 0.49 | | |
| Reflecting | Signalled and reported need for additional information | | | | | 0.48 | | |
| Reflecting | Timely notified team when encountering design problems | | | | | 0.45 | | |
| Reflecting | Constantly deliberated to accentuate design goal | | | | | 0.43 | | |
| Solutions | Taken all solutions into consideration | | | | | | −0.82 | |
| Solutions | Came up with as many solutions as possible | | | | | | −0.70 | |
| Establishing goal | Determined individual contributions in mutual consideration | | | | | | | 0.63 |
| Establishing goal | Determined sub division of design problem in mutual consideration | | | | | | | 0.51 |
| Establishing goal | Determined professional requirements in mutual consideration | | | | | | | 0.51 |
| *Eigen value* | | *10.28* | *3.00* | *2.48* | *1.97* | *1.72* | *1.36* | *1.26* |
| *Variance explained* | | *27.79* | *8.12* | *6.69* | *5.34* | *4.66* | *3.68* | *3.40* |
| *Cumulative variance explained* | | *27.79* | *35.91* | *42.60* | *47.94* | *52.59* | *56.27* | *59.67* |

*Note*. Principal axis factoring, Varimax rotation with Kaiser normalisation; factor loadings below 0.30 are not shown in the table

[a] Item lowered Cronbach's $\alpha$ from 0.87 to 0.82

On the 16 items of the two subcategories selected from the second main category 'design planning', a two-factor confirmatory factor analysis was performed ($n = 106$). Items that met the specified criteria for this category are listed in Table 5 ($n_{\text{items}} = 12$). Two factors fitted the data structure well, together explaining 50.48% of the variance in 'design planning'. The scale labels were as proposed in the data pool categorisation and only from the 'keeping schedule' category items had to be deleted. All consistency measures for both scales are well above satisfactory levels (see Table 7).

**Table 5 Factor loadings for design planning items ($n = 106$)**

| Data pool subcategory label | Item | Factor | |
|---|---|---|---|
| | | 1 | 2 |
| Keeping schedule | Adjusted individual time planning to decisions made | 0.81 | |
| Keeping schedule | Fitted additional activities into individual time planning | 0.77 | |
| Keeping schedule | Reminded each other of timely delivery of sub results | 0.76 | |
| Keeping schedule | Revised individual time planning if necessary | 0.71 | |
| Keeping schedule | Signalled divergence of sub designs | 0.70 | |
| Keeping schedule | Systematically checked whether schedule was kept | 0.59 | |
| Keeping schedule | Discussed whether time planning would be made | 0.55 | |
| Planning time | Translated overall time planning into sub design time planning in mutual consideration | | 0.85 |
| Planning time | Made individual time planning in mutual consideration | | 0.76 |
| Planning time | Made realistic overall time planning | | 0.70 |
| Planning time | Determined time required to deliver desired quality in mutual consideration | | 0.62 |
| Planning time | Determined deadline for delivery of the design in mutual consideration | | 0.44 |
| *Eigen value* | | *7.29* | *1.66* |
| *Variance explained* | | *42.74* | *7.74* |
| *Cumulative variance explained* | | *42.74* | *50.48* |

*Note*. Principal axis factoring, Varimax rotation with Kaiser normalisation; factor loadings below 0.30 are not shown in the table

On the 32 items of the three subcategories selected from the third main category 'design cooperation', a three-factor confirmatory factor analysis was performed ($n = 100$). Items that met the specified criteria for this category are listed in Table 6 ($n_{items} = 19$). Three factors fitted the data structure well, together explaining 42.62% of the variance in 'design cooperation'. The results show that the data pool subcategory 'cooperation' can be divided into two new subcategories 'cooperation' and 'reflection on team functioning', of which the latter in particular adds differentiation to the concept of cooperation. The items of factor 3 stem from two data pool subcategories 'making decisions' and 'communication'. Closer inspection of the item content reveals that one of the two communication items also deals with decisions and the other with contact frequency. Since regular contact would support the other behaviours regarding the decision-making process, we labelled the new scale 'making decisions'. All consistency measures for the resulting scales are well above satisfactory levels (see Table 7).

To get an indication of the predictive validity of the 12 DBQT scales (containing 55 items), resulting from the factor analyses, all scales were correlated with the team members' ratings of the outcome variables (originality of the design, technical realisation of the design, concepts behind the design's components, and satisfaction with the team's method of working, quality of the design, and the team itself). Results are given in Table 8. Each of the DBQT scales

**Table 6 Factor loadings for design cooperation items ($n = 100$)**

| Data pool subcategory label | Item | Factor | | |
|---|---|---|---|---|
| | | 1 | 2 | 3 |
| Cooperation | Kept informal contacts with each other | 0.78 | | |
| Cooperation | Were considerate of each other's strengths/weaknesses | 0.72 | | |
| Cooperation | Stood in for each other if necessary | 0.68 | | |
| Cooperation | Helped and supported each other | 0.66 | | |
| Cooperation | Worked on gaining mutual trust | 0.66 | | |
| Cooperation | Adjusted ourselves to each other | 0.54 | | |
| Cooperation | Established informal contacts | 0.53 | | |
| Cooperation | Showed responsibility for ups and downs of our team | 0.52 | | |
| Cooperation | Shared our knowledge | 0.41 | | |
| Cooperation | Brought each other's functioning up for discussion | | 0.89 | |
| Cooperation | Brought team's functioning up for discussion | | 0.81 | |
| Cooperation | Called our functioning within our team to account | | 0.79 | |
| Making decisions | Taken enough time to decide | | | 0.75 |
| Making decisions | Substantiated decisions | | | 0.69 |
| Communication | Reported individual decisions | | | 0.61 |
| Making decisions | Deliberated amongst each other | | | 0.57 |
| Communication | Kept in regular contact | | | 0.54 |
| Making decisions | Recorded decisions | | | 0.43 |
| Making decisions | Strove for reaching consensus | | | 0.42 |
| Eigen value | | *7.64* | *3.47* | *2.53* |
| *Variance explained* | | *23.87* | *10.85* | *7.90* |
| *Cumulative variance explained* | | *23.87* | *34.72* | *42.62* |

*Note*. Principal axis factoring, Varimax rotation with Kaiser normalisation; factor loadings below 0.30 are not shown in the table

has a significant ($p \leq 0.05$ (two-tailed)) relationship with one up to five outcomes of the design team's project.

## 3 Discussion

Based on the responses of professional multidisciplinary design team members, we constructed a data pool of critical multidisciplinary design team member behaviours (study 1) and we tested its structure, content validity, reliability (internal consistency and stability), and predictive validity, using responses of students that created an innovative design within multidisciplinary design teams (study 2). As a result we presented the DBQT, which consists of 55 items divided into three main categories and 12 subcategories. With this instrument multidisciplinary design team member behaviour that is critical to successful design task completion can be measured. We discuss our results per main category, point out weaknesses and strengths of our findings, and present practical applications and suggestions for future research regarding both the data pool and DBQT.

Structuring the interview data led to the formation of a main category 'design creation' that consisted of seven subcategories. After testing this structure, we retained seven categories, four of which with a content that slightly differed

**Table 7 Reliability of the DBQT scales: Cronbach's $\alpha$s and stability ($n = 98-106$)**

| Data pool subcategory labels ($n_{items}$[a]) | DBQT scale labels ($n_{items}$) | Cronbach's $\alpha$ concept phase | Cronbach's $\alpha$ elaboration phase | Stability[d] |
|---|---|---|---|---|
| Design creation (37) | Design creation (24) | | | |
| Establishing the design goal (6) | Design task organisation (3) | 0.61 | 0.67 | 0.62*** |
| Elaboration (5) and Information (6) | Information-based designing (5) | 0.76 | 0.79 | 0.62*** |
| Solutions (4)[b] | Building solution space (2) | $r = 0.58$*** | $r = 0.68$*** | 0.66*** |
| Solutions (4)[b] | Confining solution space (2) | $r = 0.30$** | $r = 0.25$** | 0.37*** |
| Phase transition (3) | Phase transition (3) | 0.82 | 0.88 | 0.61*** |
| Reflecting on the design (8) | Reflecting on the design (5) | 0.80 | 0.73 | 0.44*** |
| Adjusting based on reflection (5) | Adjusting based on reflection (4) | 82 | 0.79 | 0.50*** |
| Design planning (16) | Design planning (12) | | | |
| Planning time (5) | Planning time (5) | 0.82 | 0.89 | 0.55*** |
| Keeping Schedule (11) | Keeping schedule (7) | 0.91 | 0.86 | 0.47*** |
| Design cooperation (32) | Design cooperation (19) | | | |
| Cooperation (13)[c] | Cooperation (9) | 0.86 | 0.86 | 0.52*** |
| Cooperation (13)[c] | Reflecting on team functioning (3) | 0.88 | 0.87 | 0.41*** |
| Making decisions (6) and Communication (13) | Making decisions (7) | 0.81 | 0.89 | 0.50*** |

[a] After condensing the original categories
[b] Scales are identical
[c] Scales are identical
[d] Correlation between designers' responses in the concept phase and elaboration phase. **$p \leq 0.01$; ***$p \leq 0.001$

from the initial classification. The content of the DBQT subcategory 'design task organisation' surprised us in the sense that behaviours concerning establishing the design goal did not turn out to be considered essential for the design process. Both problem-solving theories (e.g., Newell and Simon, 1972; Dörner and Wearing, 1995) and results of other studies into designing in teams, however, point to their importance (e.g., Badke-Schaub and Frankenberger, 2002). An explanation for this may lie in the fact that the assignment, and thus the design goal, was already clear to the students and had therefore not to be discussed. The team's discussion did focus on how to achieve the goal given the constraints of the assignment and their team. This latter discussion is reflected in the DBQT's 'design task organisation' category that emerged, category which is related to the satisfaction outcome variables of the teamwork.

The differentiation between 'information gathering' and 'elaboration of the design' as suggested by the framework resulting from the data pool did not hold when tested. These two aspects of the design process appeared to be connected. This was a less surprising finding, given the iterative nature of design processes. Elaborating the design without taking notice of new information originating from the progress of the design thus far or from external sources

**Table 8 Intercorrelations between DBQT scales and self-rated design outcomes ($n = 90$)**

| | Team members evaluation of Outcomes | | | Team member satisfaction with Outcomes | | |
|---|---|---|---|---|---|---|
| DBQT scales | OR | TR | CC | MW | QD | T |
| Design task organisation | | 0.32** | 0.22* | 0.28** | 0.27** | 0.25* |
| Information-based designing | | 0.45*** | | 0.36*** | 0.31** | 0.32** |
| Building solution space | | | 0.22* | | | |
| Confining solution space | 0.32** | | | | | |
| Phase transition | | | | | | |
| Reflecting on the design | | 0.28** | | | | |
| Adjusting based on reflection | | | | | 0.21* | |
| Planning time | | 0.28** | | 0.24* | | |
| Keeping schedule | 0.26* | 0.35** | 0.23* | 0.25* | 0.21* | |
| Cooperation | | | | | | 0.21* |
| Reflecting on team functioning | 0.30** | | | | | |
| Making decisions | | | | | 0.23* | |

Non-significant correlations are not shown in the table; $*p \leq 0.05$ (two-tailed); $**p \leq 0.01$ (two-tailed); $*** \ p \leq 0.001$ (two-tailed). OR = the originality of the design; TR = the technical realisation of the design; CC = the concepts behind the design's components; MW = the method of working; QD = the quality of the design; T = the team

would be unwise, to say the least. To reflect this entangledness, we relabelled the emerged DBQT category 'information-based designing'. Given the fact that in many design-team-related studies only the processes that lead to the concept of the design are studied, we feel that the fact that this study shows that 'information-based designing' behaviours also relate to the elaboration of the design is of added value. Its importance is shown through the relationships it has with both design-related and team-related outcomes.

The opposite effect appeared with regard to the solution-related behaviours. These were all classified under a single heading in the data pool categorisation, but testing that structure showed two dimensions underlying this category, namely 'building the solution space' and 'confining the solution space'. Considering the limited number of behaviours in the initial scale, we did not expect a refinement of this data pool subcategory, but distinguishing between these aspects is in line with problem-solving and design-process theories (Carroll and Johnson, 1990; Dörner, 1996; Lipshitz and Bar-Ilan, 1996; Pahl et al., 1996) and shows up in previous design team research too (Badke-Schaub and Frankenberger, 2002; Stempfle and Badke-Schaub, 2002). Apparently this differentiation is very profound and thus even shows itself for the few solution-related behaviours that were included. This refinement enriches the data pool categorisation, especially since both processes relate to different outcomes. However, the fact that the number of behaviours in both DBQT subcategories is rather small is an undesirable characteristic of a measurement scale from a methodological point of view.

The other subcategories 'phase transition', 'reflecting on the design', and 'adjusting based on reflection' were condensed, but the behaviours were all in line with the data pool subcategory headings. The importance of reflection and acting upon it has been established in a number of studies (e.g., West, 1996; Valkenburg, 2000; Reymen, 2001) and also shows from our results: both dimensions adhere specifically to the design team members' rating of outcome quality. The finding that consciously making the transition between two design process phases is of importance underpins findings of Stempfle and Badke-Schaub (2002). This showed that for complex problems transitions between generating, analysing, and evaluating ideas have to be made in order to arrive at satisfying solutions (p. 491). Our result expands their findings in the sense that these transitions have to be made consciously.

For the main category 'design planning', the initial categorisation structure was retained after statistical testing. Only four items had to be discarded and the content of the remaining behaviours represented both data pool subcategories 'planning time' and 'keeping schedule'. Both DBQT scales showed robust psychometric qualities and were related to almost all outcome variables included in our study.

For the main category 'design cooperation', three subcategories appeared after testing the data pool structure, but – as with the 'design creation' category – some rearranging and relabelling within the data pool's three-category structure was suited. Within the rather large data pool subcategory 'cooperation' two subcategories could be distinguished. The first DBQT subcategory 'cooperation' fits the data pool subcategory 'cooperation' perfectly, but the second one 'reflection on team functioning' proved to be a refinement within the data pool subcategory itself. Not only does this newly established DBQT subcategory underline the previously noted importance of reflection during designing, it also shows that reflecting on the team's functioning is different from reflecting on the design, as they both relate to different outcomes. Distinguishing between both forms of reflection corresponds with West's (1996) work on reflexivity in teams. In spite of the logic behind distinguishing between the two forms of reflective behaviours, the fact that each form of reflection stems from a different analysis calls for the need of substantiation of this finding in future design team research.

The subcategory 'making decisions' was retained after testing, but some behaviours that were classified under the data pool subcategory 'communication' were added to it, because they also supported the decision-making process. The fact that decision-making falls under the heading of this main category has to do with the general formulation of the decision-making behaviours. In both the problem-solving and the design literature, arriving at a decision is the end phase of the problem-solving or design process, but from the interviews with the designers it appeared that decisions had to be regarded from a broader perspective: decisions also concern planning the design process and cooperating within the design team. Results obtained when testing the data pool structure confirm this general approach. The DBQT subcategory ‘making decisions’ is related to the designers’ perception of the quality of the design.

That an important data pool subcategory like ‘communication’ had to be discarded from the final DBQT may be explained by the fact that communication is implicit to a large number of behavioural items in the DBQT (e.g., ‘in mutual consideration’, ‘deliberated’, ‘notified and reminded each other’, and ‘signalled and reported’). Since communication is considered to be important throughout the whole of the design process (Dorst, 2003; Eckert and Stacey, 2001; Stempfle and Badke-Schaub, 2002), we think it is better to have communication represented in each behavioural DBQT subcategory as is the case now, than as a single stand-alone subcategory like in the framework based on the data pool.

We conclude this part of the discussion with an answer to the research question. The two studies we have conducted provided us with a large number of behaviours that appear to be critical for a variety of outcomes that adhere to successful design task completion. The structure that can be imposed upon these behaviours is comprehensive, to a large extent statistically replicable, and in line with results of studies into single aspects of the design process.

Throughout the discussion of each of the main categories some limitations of this research have already been addressed. In our opinion the three most important limitations concern the number of respondents, the kind of teams in the second study, and the measurement of the outcomes of the teamwork. To start with the number of respondents, the ratio between the number of respondents and number of items we performed factor analysis upon was a bit unfavourable. If in future studies the sample is larger, this will firstly allow for a test of the complete data pool structure at once, instead of each of the three main categories separately. Secondly, it might alter the content of the DBQT subcategories by increasing both the number of subcategories and the number of items in each of the subcategories. Finally, it may increase the reliability of the DBQT’s ‘design task organisation’ category, which is somewhat below acceptable levels.

Although the conditions under which the teams in the second study had to work were representative of designing in general (an open assignment, restricted resources, a strict deadline, the outcome was of importance to the team members), the characteristics of the teams studied might restrict the generalisability of the DBQT. The teams under study (a) were self-managed, (b) were composed of relatively inexperienced designers, (c) worked on innovative design assignments, (d) did not interact directly with a client, (e) worked together for a relatively short period of time, and (f) consisted of members who interacted frequently. For teams with characteristics that deviate from those described above, the validation process will have to be repeated. Given its comprehensiveness the data pool is a good point of departure from which relevant categories or items can be selected and tested following the process described in study 2. For mono-disciplinary design teams both studies need to be redone. Since knowledge and skills of mono-disciplinary design team members can be expected to be more restricted, other behaviours for successfully accomplishing the design task may be critical.

Finally, with regard to the predictive validity of the DBQT, it will be important to relate DBQT process ratings to design outcomes rated by other people than the design team members themselves, since this may have led to distortion of results due to common method (percept—percept correlations) or single source variance.

One of the strengths of our study clearly is the integrative approach we took to analysing the design process. The resulting instrument reflects this. Not only did we address the design creation or problem-solving processes needed to arrive at a successful design, but via task analysis the planning and social processes which are crucial for designing were also represented in the data pool and included in the final questionnaire.

Another strength of our study is the fact that the DBQT has a wide range of applications. The fact that the DBQT can be scored by both design team members themselves and external raters (like researchers, managers, or educators) allows for a comparison of the different ratings, which may provide interesting information in itself. Furthermore, the DBQT can be used for research, practice, or education on designing. For research purposes, the DBQT offers means to quantitatively study relationships between (a) different design behaviours, (b) antecedents of design behaviour (e.g., knowledge, skills, attitudes, and other characteristics of designers or characteristics of the design team) and design behaviours (King and Anderson, 1999), and (c) design behaviour and design outcomes (e.g., timeliness, quality, or personal outcomes for designers). In our review of the literature we found no study that offered such an instrument, nor one that addressed the relationship between antecedents and design behaviour. We found only one study that addressed the relationship between design behaviour (communication) and outcomes (Badke-Schaub and Frankenberger, 2002). For practical purposes, the information obtained with the DBQT can be used by (student-)design team members: it can enlarge their awareness of critical design process dynamics and their relationships with antecedents or outcomes via focussed reflection, and thus serve to improve design processes (Reymen, 2001; Stumpf and McDonnell, 2002). It can also be used by managers, or leaders of (student-)design teams: they can either manipulate antecedents (e.g., team composition in terms of team member expertise (Atman et al., 1999, 2005) or team member personality (Kichuk and Wiesner, 1997)), alter aspects of the design process, or educate design team members by assigning them to suitable training programmes. Finally, for educational purposes, information obtained via the DBQT can be used to tailor educational programmes to the most important aspects of teamwork or to specific needs of student designers.

A final strength concerns the content validity of the DBQT. The fact that we collected from professional team members with various backgrounds critical behaviours, of which the importance and structure reappeared when testing them in student design teams, demonstrates that our results can be generalised. We therefore express the hope that the DBQT will be used as both a research tool and a tool to reflect upon design team functioning in (educational) practice. This will increase our knowledge on design team processes and their relationships with antecedents and outcomes.

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1. The complete list of behavioural items is available upon request from the first author.