

# **A COMPARISON OF DESIGN ACTIVITY OF ACADEMICS AND PRACTITIONERS USING THE FBS ONTOLOGY: A CASE STUDY**

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## **ABSTRACT**

Academics teach engineering design based on design theory and best practices, practitioners teach design based on their experience. Is there a difference between them? There appears to be little prior work in comparing the design processes of design academics and practitioners. This paper presents a case study in which the design activity of a team of academics was compared to that of a team of practitioners. The participants' verbalizations during team discussions were coded using the Function-Behaviour-Structure (FBS) ontology. A qualitative comparison reveals that the team of practitioners constructs the design space earlier and generally spends more time in the solution space than the team of academics. Further, the team of practitioners has a significant number of direct transitions from function (F) to structure (S), while no such transitions are observed for the team of academics. Given that this is a single case study, the results cannot be used as the basis for any generalizations on how academics and practitioners compare. This is a successful proof of methodologies that lay the foundation for a series of hypotheses to be tested in a future study.

**Keywords:** Design cognition, Design practice, Design process, Design theory, Ontologies

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## 1 INTRODUCTION

In the professions, there seems to be a natural and enduring tension between theory and practice, between academics and practitioners. We can recall several sayings that humorously lament this apparent contrast. In the medical profession, this has been colloquially characterized as a tension between the *bench* and the *bedside*. This tension, this duality, is present also in the profession of engineering and in the discipline of design (Norman, 2010). The communities co-exist and perform important work in their respective cultures. It is not uncommon for educators in some engineering programs to be mostly academics without significant experience in professional practice. This is especially the case in the discipline of design. Similarly, some engineering programs hire practitioners to teach design without formal academic education in the discipline of design. We are interested to determine what the implications of this situation are on the teaching, learning and assessment of design. As an initial step we aim to study the differences between academics and professionals designing. In particular, we seek to answer the following research questions: (1) Do academics and practitioners design differently?, and (2) If they do, what are the differences?

In this paper we describe a preliminary investigation of how the design activity of academics and practitioners might be compared. The rest of the paper is structured as follows. In Section 2 we provide a brief literature review on the differences between academics and practitioners and the FBS ontology of describing design activity, as this is used to analyze the source data. In Section 3 we describe the data collection and analysis method. In Section 4 we summarize the results of the analysis. Finally, in Section 5, we discuss the study's contribution and limitations including hypotheses to be tested in a full study.

## 2 BACKGROUND

Our experiences observing academics and practitioners, and in designing ourselves, suggest that a difference may indeed exist between how academics and practitioners design. This has important implications in the teaching of design, where instructors may be academics and/or experienced practitioners. A better understanding of these differences has the potential to affect the pedagogical decisions we make in designing learning activities, teaching methods and learning contexts, as well as designing effective curricular sequences and structures for facilitating the mastery of design.

### 2.1 Literature review

A survey of the literature reveals surprisingly little prior work on comparing how academics and practitioners approach design problems. However, there is broad recognition regarding the academic versus practitioner gap across many disciplines, including Information Technology (IT) systems analysis (Anandarajan and Lippert, 2006; Lippert and Anandarajan, 2004), Human-Computer Interaction (HCI) (Colusso *et al.*, 2017), management sciences (Bartunek and Rynes, 2014; Mohrman, Gibson and Mohrman Jr., 2001), mathematics and statistics (Goos, 2014; Belli, 2010), ergonomics and human factors (Chung and Shorrock, 2011; Chung, Williamson and Shorrock, 2014), eating disorders (Lilienfel *et al.*, 2013), and autism research and clinical practice (Parsons *et al.*, 2013).

These different communities subjectively generate and consume knowledge in terms of their own “thought-worlds”, interpretive conventions, and specific social processes (Mohrman *et al.*, 2001). In IT systems planning, it is reported that academics take a long term view and focus on error prevention, while practitioners take a shorter term view emphasizing completion of tasks and solution-specific problems (Lippert and Anandarian, 2004). Practitioner information seeking behavior favors oral over written communications and a reliance on experience and consultation with coworkers and supervisors, until the problem complexity increases and they then consult written sources (Fraser *et al.*, 2018).

### 2.2 Function-Behaviour-Structure ontology

Function-Behavior-Structure ontology, also known as FBS, (Gero, 1990; Gero and Kannengiesser, 2014) has been used as a design ontology that describes all design, regardless of design context, discipline, or setup. The FBS ontology was chosen as it has been used widely in protocol analysis (Kan and Gero, 2017) and has been used to analyse over 10,000 hours of designing in industry (Bott and Mesmer, 2019). The FBS framework describes design using 6 fundamental elements, called design issues, which

represent cognitive activations: Function (F) represents designers' intentions for the products. Structure (S) represents the design components and their relationship to each other. Expected behavior (Be) represents a set of performance criteria used as benchmarks for the design structure. Behavior from structure (Bs) is the set of performances that are measured or derived from structure. Requirements (R) are expectations from the client that come from outside the designer usually in the form of a task statement. Finally, description (D) represents a depiction of the design created by the designer. The FBS framework represents the processes of designing as transformations between the six design elements that result in eight fundamental design processes - representing cognitive effort, as shown in Figure 1.

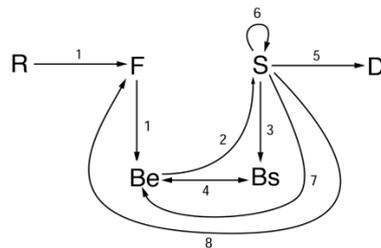


Figure 1: The FBS framework

*Formulation* (process 1) transforms the design requirements, expressed in function (F), into behavior (Be) that is expected to enable this function. *Synthesis* (process 2) transforms the expected behavior (Be) into a solution structure (S) that is intended to exhibit this desired behavior. *Analysis* (process 3) derives the “actual” behavior (Bs) from the synthesized structure (S). *Evaluation* (process 4) compares the behavior derived from structure (Bs) with the expected behavior (Be) to prepare the decision if the design solution is to be accepted. *Documentation* (process 5) produces the design description (D) for constructing, manufacturing or implementing the product (S). *Reformulation type 1* (process 6) addresses changes in the design state space in terms of structure variables or ranges of values for them if the actual behavior is evaluated to be unsatisfactory. *Reformulation type 2* (process 7) addresses changes in the design state space in terms of behavior variables or ranges of values for them if the actual behavior is evaluated to be unsatisfactory. *Reformulation type 3* (process 8) addresses changes in the design state space in terms of function variables or ranges of values for them if the actual behavior is evaluated to be unsatisfactory (Gero and Kannengiesser, 2014, p. 3).

### 3 METHOD

A study was conducted during a workshop at a recent design conference (Nespoli and Isaksson, 2018). The workshop featured a reference case study and accompanying video exhibit of a real design challenge (MacDonald *et al.*, 2015). Participants were introduced to the purpose of the workshop, and asked to self-select into four teams of academics and practitioners. The facilitator introduced the design challenge, played the video exhibit, and answered questions. Workshop participants were then asked to read the case study individually first (for approximately 15 minutes) and to then solve it in their teams (for approximately 45 minutes). All teams were asked to audio record their discussions as they worked to solve the design challenge. At the end of the workshop, each team had to give a short presentation of their designs and to submit all design representations to the facilitator. It is recognized that this is a laboratory-type experiment rather than an in-situ study.

The audio recordings of just two teams' discussions - one composed of four academics and one composed of four practitioners - were available and of sufficiently good quality to be transcribed. The transcriptions were coded by two individual coders and one arbitrator using the FBS coding scheme, following a process as presented in Figure 2. Coder1 first segmented the text based on occurrence of FBS issues. In the coding phase, Coder1 and Coder2 coded the segments independently and revised the segmentations when required. Next, in the arbitration phase, codes and segmentations were compared between coders. At this stage, the two coders marked down their coding and segmentation disagreements for a future decision. Finally, the data along with the disagreements was passed to the final arbitration session, during which the arbitrator discussed the disagreements with the coders and made a final decision on them. The agreement rate between coders and the final arbitrated version averaged 85%. We use this measure instead of Cohen's kappa as we are not comparing coders with each other, but rather with the arbitrated version.

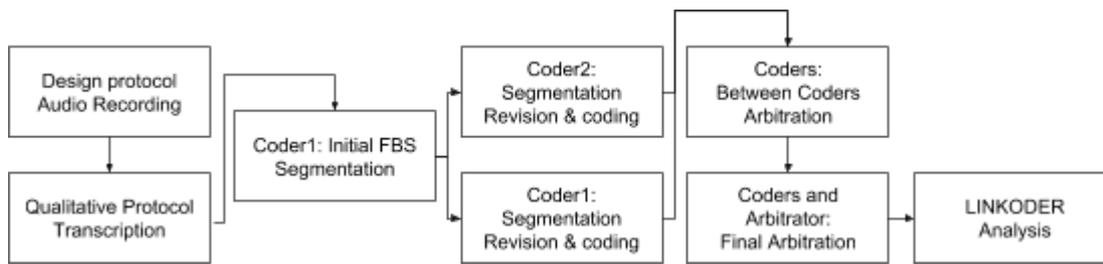


Figure 2: FBS coding and arbitration process

It should be noted that since coding was only based on audio recordings and transcripts, the design issue of description (D), which is detected through gestures or other visual cues, was not detected in a reliable way. Therefore, the analysis described in the Results section does not include the issue of D or the process of Documentation. Once final arbitrated codes were achieved for both teams, coded segments were analysed using the LINKODER tool to produce a number of analyses and statistics, as described by Pourmohamadi and Gero (2011).

## 4 RESULTS

### 4.1 Design issues

The distribution of design issues for the two teams (from a total of 528 and 578 design issues for academics and practitioners, respectively) is presented in Figure 3. Qualitatively, we can observe some differences between the two teams - especially in the percentage of Be, which is higher for the team of academics. The team of practitioners has higher percentages of Bs and S.

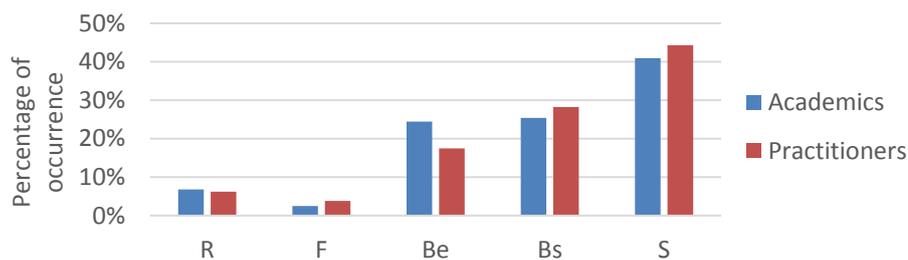


Figure 3: Occurrence of design issues (expressed as a percentage) for the team of academics and the team of practitioners

Next we present the distributions of occurrences of design issues over time, Figure 4. Qualitatively, we can observe that the distributions for the two teams are different. In the first half of the session, the team of practitioners has higher frequencies of S and Bs compared to the team of academics. In addition, we observe that the design issue of F occurs throughout the session for the team of practitioners, whereas for the team of academics it is absent in the middle portion of the session.

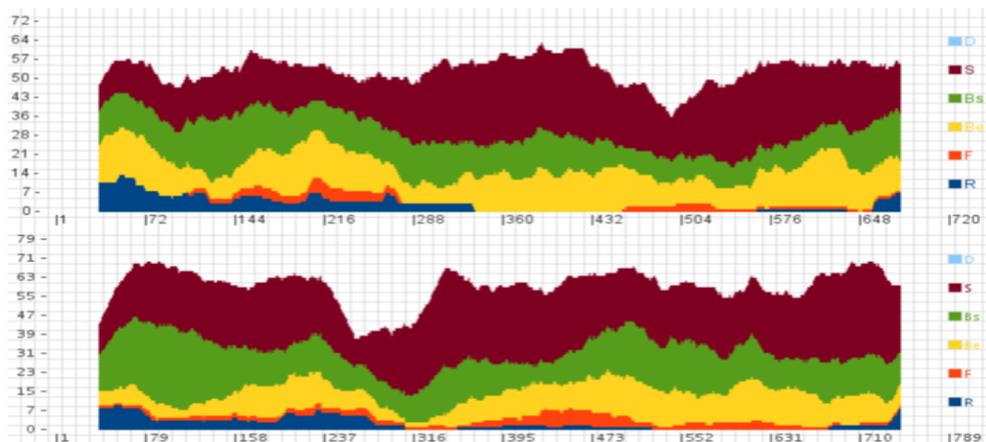


Figure 4: Number of occurrences of design issues over time for the team of academics (top) and practitioners (bottom)

To better investigate the change over time, we compare the percentage of occurrence of design issues over the first and second halves of the session for both teams, Figure 5. It is observed that the team of academics increases the percentage of S and decreases the percentage of R. In contrast, for the team of practitioners, the percentage of S remains virtually unchanged.

We also compare the distribution of design issues between the two teams in both the first and second halves of the session, Figure 6. In the first half of the session, compared to the team of academics, the team of practitioners has a larger percentage of S, and a smaller percentage of Be. In contrast, the difference between the two teams in the second half of the session appears to be smaller.

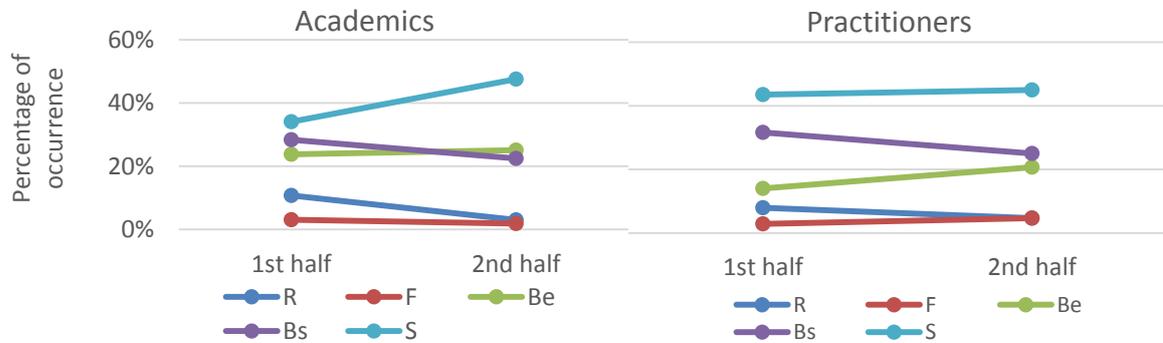


Figure 5: Comparison of occurrence of design issues (expressed as a percentage) between the first and second halves of the sessions for the teams of academics and practitioners

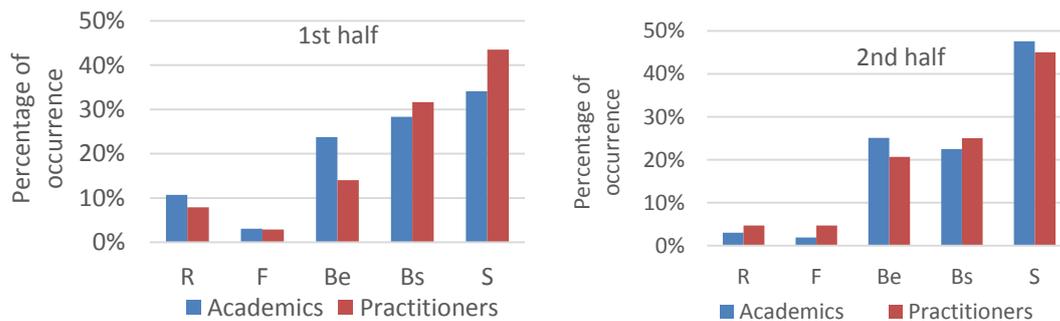


Figure 6: Comparison of occurrence of design issues (expressed as a percentage) between the two teams in the first and second halves of the sessions

## 4.2 P-S Indicator

Another measure that we can use to describe design activity is the moving P-S Indicator, which describes temporal changes to the variation of focus in the problem and solution spaces (Milovanovic and Gero 2018). We calculate the P-S indicator as the difference between the sum of problem-related design issues (R, F, Be) and the sum of solution-related design issues (S, Bs), all divided by the number of segments in the window of concern. A positive P-S Indicator indicates the focus is on the problem space, whereas a negative value indicates the focus is on the solution space. Values of the P-S indicator are robust as they cover hundreds of design issues.

First, we investigate the P-S indicator for the entire session as well as in the two halves of the session. The P-S indicator is -0.33 for the team of academics and -0.45 for the team of practitioners. This implies that the team of practitioners is more focused on the solution space than the team of academics. For the team of academics, between the first and the second halves of the session, the P-S indicator drops from -0.25 to -0.40. In the same time frame, for the team of practitioners, the P-S indicator increases from -0.50 to -0.40. This implies a different temporal behavior between these two teams. It is noted that both groups have the same P-S indicator in the second half of the session; however, we require a larger dataset to determine if this congruence is meaningful.

Using a window size of 1/10 of the total number of FBS segments, we graph the moving P-S Indicator as shown in Figure 7. Both teams are solution focused; this is particularly the case for the team of practitioners, for which the P-S indicator is negative throughout the session. Another difference is observed with regards to the trend of the P-S indicator: while for the team of academics the trend is

downwards, suggesting a slow general move from the problem-space to the solution-space, for the team of practitioners the trend is slightly upward, suggesting a solution-first approach.

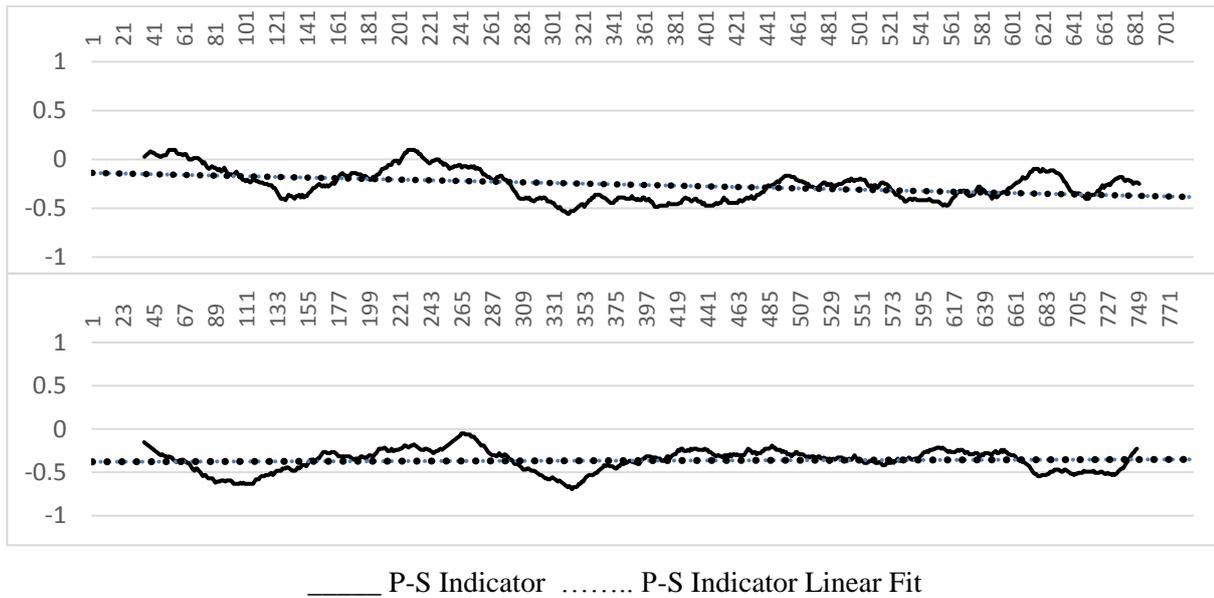


Figure 7: Moving P-S Indicator for the team of academics (top) and practitioners (bottom)

### 4.3 Design processes

The distribution of design processes for the two teams is presented in Figure 8. Overall, we observe only some small differences, most notably for Synthesis, Analysis, Evaluation, Reformulation 1 and Reformulation 2.

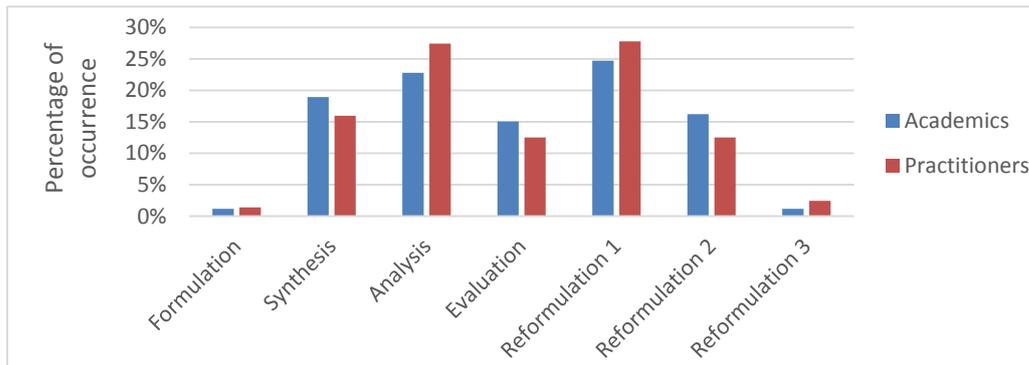


Figure 8: Occurrence of design processes (expressed as a percentage) for the group of academics and the group of practitioners

We also observe the changing frequencies of design processes over time, as shown in Figure 9. It is difficult to qualitatively compare the two graphs, though we observe some noticeable differences - both between and within groups - particularly in the changing distributions of Analysis, Reformulation 1, Evaluation and Reformulation 2.

We further investigate the change in occurrences of design processes in the second half of the session compared to the first half. The differences between the two halves of the session are presented in Figure 10. For the team of academics, the largest change is the increase in Reformulation 1. In contrast, for the team of practitioners, while there is some change for all design processes - most increase slightly, except for Analysis, which decreases - overall, the change appears to be small.

In order to show the difference between the two teams in each part of the session, we plot the design processes as adjacent histograms, as shown in Figure 11. In the first half of the session, compared to the team of academics, the team of practitioners has more Analysis and Reformulation 1 and less Synthesis, Evaluation, and Reformulation 2. In the second half of the session, the differences between the two teams are less pronounced.

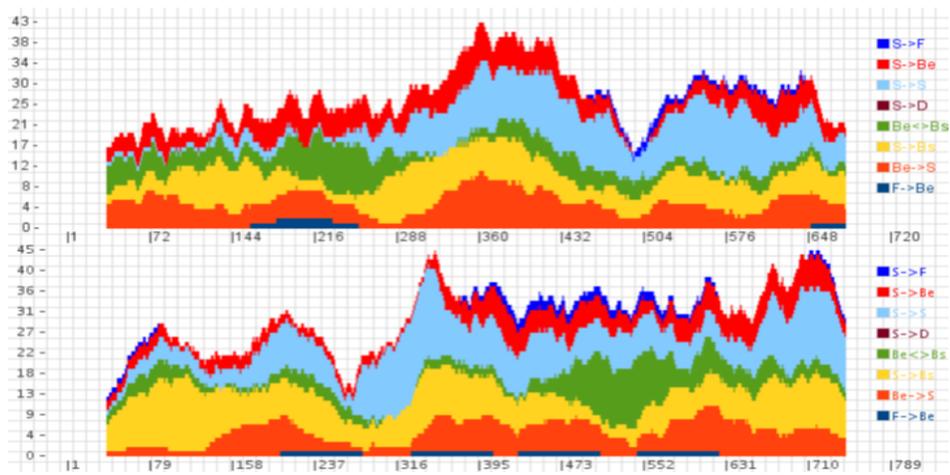


Figure 9: Number of occurrences of design processes over time for the team of academics (top) and the team of practitioners (bottom)

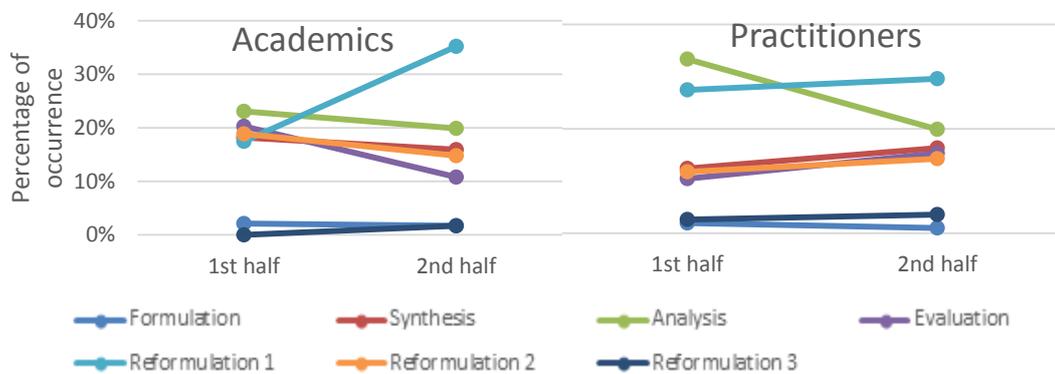


Figure 10: Comparison of occurrences of design processes (expressed as a percentage) between the first and second halves of the sessions for the team of academics and the team of practitioners

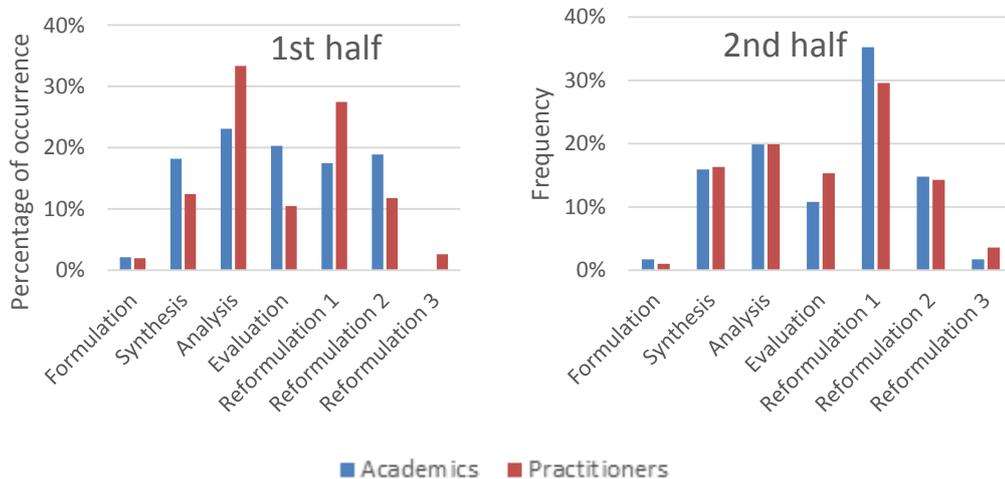


Figure 11: Comparison of occurrences of design processes (expressed as a percentage) between the team of academics and the team of practitioners in the first and second halves of the session

#### 4.4 1st order Markov Model

We constructed a 1st-order Markov Model to investigate the probability of transitioning between the various design issues, shown as rows to columns in Table 1. Overall, the models appear similar between the two teams. One important transition difference that is that the probability of transition

from F directly to S is 0.19 for the team of practitioners and 0 for the team of academics. The significance of this will be discussed later.

Table 1: 1st order Markov Model for the team of academics (left) and practitioners (right)

	R	F	Be	Bs	S
R	0.48	0.03	0.13	0.26	0.10
F	0.00	0.33	0.50	0.17	0.00
Be	0.02	0.03	0.32	0.18	0.45
Bs	0.08	0.02	0.18	0.24	0.48
S	0.02	0.02	0.25	0.34	0.37

	R	F	Be	Bs	S
R	0.38	0.04	0.12	0.17	0.29
F	0.12	0.06	0.25	0.38	0.19
Be	0.05	0.01	0.21	0.19	0.54
Bs	0.04	0.02	0.14	0.22	0.57
S	0.04	0.03	0.17	0.38	0.38

## 5 DISCUSSION

Design instructors teach students the design process and coach them in their design activities. They base their teaching and doing of design on design theory and best practices. It is assumed that these practices model the design activities of design practitioners. The question that prompted this investigation was whether academics and practitioners did design differently, and if so, in which ways they might differ. The differences could relate to both the process and outcomes of design, and would have implications for how they teach and evaluate design. Our review of the literature found little prior work on comparing the design activity of academics and practitioners. This paper represents a preliminary investigation into how the design activity of engineering (design) academics and practitioners might be studied and compared. In our case study, two teams of four participants each - one self-identifying as composed of academics and one as practitioners - worked to produce a design for a set of requirements, presented as a case. Transcripts of their discussions were coded using the FBS ontology, abstracting each team's discussion to a series of over 500 design issues, providing a large dataset for analysis.

We cannot make generalizations from this case study, only observations. This was a successful application of methodologies adopted to gather data and to analyse it to show differences between these two teams. The use of a design problem expressed in the form of a case study was shown to be an adequate prompt for eliciting design activity from both groups (Rynes *et al.*, 2001). A future study would seek to repeat the approach with a statistically significant number of teams to investigate the extent of differences between the academics or practitioner teams. This case study lays the foundations for and provides some preliminary evidence on which to construct hypotheses for a future study, as the differences between academics and practitioners has not been adequately studied previously.

With regards to the methodology, the most promising analysis on which to base the comparison between academics and practitioners appears to be on the temporal changes of design activity, as captured by changes in design issues, design processes and the P-S indicator. Overall, the most pronounced differences in design issues between the two teams in this study occurred in the first half of the session, where the team of practitioners has more S and less Be than the team of academics. Over the course of the session, the team of academics increased the frequency of S and decreased the frequency of R, while the team of practitioners increased the frequency of Be and decreased the frequency of Bs. These trends are also captured by the moving P-S indicator, which shows that while both teams spend most of their time in the solution space, this is more the case for the team of practitioners than the team of academics. These differences are also reflected in the design processes, especially in the first half of the session, where, compared to the team of academics, the team of practitioners engages more in the processes of Analysis and Reformulation 1 (both in the solution space) and less in Synthesis, Evaluation, and Reformulation 2 (which connect the solution space to the problem space). Overall, the distribution of design processes for the team of practitioners does not change between the first and second half of the session, whereas for the team of academics, we observe a large increase in Reformulation 1. All of the above point at potentially different ways in which the two teams in this study conducted their design activity. The most pronounced difference occurs in the beginning stages of design, where the team of academics takes a (closer to theory) problem-focused approach before moving towards the solution space. In contrast, the team of practitioners constructs the solution space almost immediately, exhibiting a pattern of behaviour that is regularly observed, but is not necessarily prescribed (Kannengiesser and Gero, 2017). Based on the above, we construct the following two hypotheses:

*H1: Practitioners begin to construct their solution space earlier than academics*

*H2: Practitioners spend a greater portion of their design activity in the solution space.*

A final technique that was used in this study was the 1st order Markov Model. In particular, it is observed that the team of practitioners moves from F to S with 19% probability, whereas for the team of academics that probability is zero. This is potentially a significant finding. According to Kannengiesser and Gero (2018a) the direct transition from F to S is indicative of the reflexive translation (or pattern matching) of functions (stimulus) into known solutions (structures), without first interpreting those functions as behaviours. This is known in cognitive science as System 1 thinking. It is hypothesized that design practitioners have more F to S transitions, due to their accumulated experience; however, a prior study comparing designers with students has not provided support for it (Kannengiesser and Gero, 2018b). This case study provides some limited support for this hypothesis. Therefore a third hypothesis that a future study might test is:

*H3: Practitioners exhibit more System 1 thinking (as exhibited by the frequency of F>S transitions) than academics.*

While we found some differences in the design activity of the two teams, we do not know if one team's process was superior, as judged by the outcomes of that process as we did not evaluate the artifacts produced by the teams. However, other studies have found that compared to novices', practitioners' designs are more useful but less novel (Christiaans and Venselaar, (2005). As such, in a future study we could also test the following two hypotheses:

*H4: Practitioners' designs exhibit greater utility than academics' designs*

*H5: Practitioners' designs are less novel than academics' designs*

Beyond increasing the sample size and evaluating the design outcomes, a future study would also improve on the present methodology in two other ways. First, in this case study, we gathered little information about the participants, beyond their self-identification as belonging to one of the groups. We might be interested to know about their years of experience (whether in industry or academia), scope of practice, and discipline of this practice. In a future study, participants would complete a pre-study questionnaire to find the answers to these questions. Second, in this case study only audio recordings of the design activity were captured. Viewing of the video recording, in conjunction with reading the activity transcript, creates a more complete picture for coders; this is especially the case when participants are engaging in non-verbal communication, such as drawing, pointing, or other gesturing. In a future iteration of this study, video data would be captured in addition to audio.

## 6 CONCLUSION

The case study described in this paper compared the design activity of a team of practitioners and a team of academics. Overall, it found that the team of academics followed a problem-then-solution approach, while the team of practitioners focused their efforts directly on the solution. Given that this is a single case study, the results cannot be used as the basis of any generalizations on how academics and practitioners compare. However, the processes used to produce results and its findings will be used to design experiments and hypotheses for future studies that are aimed at elucidating the design differences of academic and practitioner design teachers and the impact on design pedagogy of those differences by measuring student design cognition and outcomes.

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