Functional Thinking: A Protocol Study

An Evaluation Rubric for Function Structures

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1. Background and Motivation

Function modeling is a tool that can be used to map functional requirements of a design problem to the solution space. Research has ben done on developing general methods to create function models [1],[2]. However, there is a lack of research focused on understanding how designers create function models. The motivation behind this research is to fill this gap. The goal of this research is to understand how engineering designers think about mechanical functions by studying their behavior during a function modeling activity.

2. Current Methods

A protocol has been established by previous work in this area. The protocol study is done in an experimental setup as shown in figure 1. A video of the function modeling activity is recorded and later encoded for pattern analysis. The encoding process consists of an element encoding, where each element drawn by the designer is identified and classified; an activity coding which monitors addition, removal or editing of elements; and a topology coding which monitors the sequence of actions.

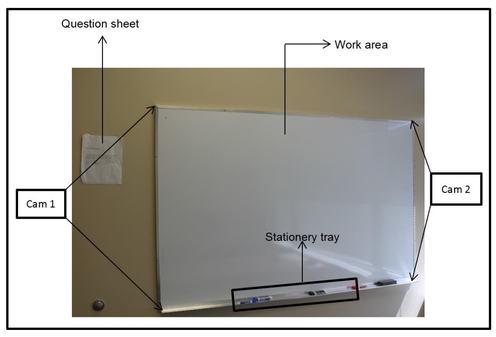

Figure 1: Experimental Setup

3. Research Plan

This research will build on the previous work done in this area. The following work is planned

- Improve the experiment protocol
  - Create a rubric to evaluate function models. This rubric should have objective measures to evaluate the function structures and have a high agreement between raters
  - Incorporate a whiteboard capture system to record the drawing progression.
  - Investigate method to capture participant background and determine the effects of individual differences on the way the function structures are modeled.
- Conduct the experiment with more participants
  - Increase the number of participants in order to have a statistically significant sample size and capture any differences in modeling techniques that may not be apparent from using less than 10 participants.
  - Increase the number of models per participant in order to avoid model bias and to evaluate the impacts of learning.
- Investigate cognitive theories regarding modeling to help understand the results from the studies.
- Conduct a supplementary study to understand the effects of seeding on function structures generated by students.

4. Preliminary Results

In order to improve the experiment protocol, a method to evaluate function structures was explored. A scoring rubric for function structures is provided by Nagel et al in [3]. This rubric was applied to the function structures generated in the previous studies. Questions presented in this rubric are shown in figure 2.

1	Model contains a black box?
2	Black box contains input and output flows?
3	Are the input and output flows in the black box appropriate?
4	Does the black box represent flow conservation?
5	Do inputs from the black box match functional model inputs?
6	Do outputs from the black box match functional model outputs?
7	Does the functional transformation described by the black box represent a plausible overall system functionality?
8	Does the black box function–flow pair take the general form a verb/noun pair?
9	Do the function–flow pairs in the functional model overall represent a plausible view of the product?
10	Do the function–flow pairs in the functional model take the general form of a verb/noun pair?
11	Is the functional model free of nonsensical functions?
12	Is the functional model free of nonsensical flows?
13	Is the model free of instances where the system acts on the system?
14	Is flow directionality consistent with the transformation in the functions?
15	Are flows conserved across function transformations?
16	Are flow paths appropriate for product representation?
17	Does the functional model represent flow conservation?
18	Are the proper energy, material, and signal flow arrow conventions followed?

Figure 2: Evaluation questions presented in [3]

- These questions were used to rate 8 function structures by 3 separate raters
- An inter rater analysis was performed using Cohen's kappa as the measure for inter rater agreement.
- Fair agreement between rater 1 and 2 and between rater 2 and 3 was found
  - $k_{12} = 0.24$ and $k_{23} = 0.33$

The results obtained from evaluation using rubric shown in figure 2 is unsatisfactory. This may be due to the following reasons.

- Raters provide a 0 or 1 rating for each question. This forces the raters to condense the information in the function structure to a binary score.
- Some of the questions in the rubric are subjective leading to a difference in ratings that may not be based on the model, but rather the rater's perception of the model.

5. Proposed Evaluation Rubric

In order to improve the agreement between raters, a modified rubric has been developed. This rubric is focused on objective questions and allows the raters to provide a range of scores for each question.

1	Number of input flows in the blackbox
2	Number of output flows in the blackbox
3	Number of flows in the blackbox that are labeled in appropriately
4	Number of input flows in the blackbox that match the functional model
5	Number of output flows in the blackbox that match the functional model
6	Number of function-flow pairs in the blackbox that take the general form of a verb/noun pair
7	Number of functions in the functional model
8	Number of flows in the functional model
9	Number of function-flow pairs in the functional model that take the verb/noun form
10	Number of functions that make sense
11	Number of flows that make sense
12	Number of functions that do not act on the system
13	Number of flows consereved across the functional transformations
14	Number of flow arrows clearly identified as material/energy/sigmal

Figure 3: Modified Evaluation questions

Figure 3 shows the questions that are used in the modified rubric.

- These questions are focused on extracting the same information as the original rubric.
- Questions 1,2,7 and 8 are used as reference for all other questions.
- Ratios are calculated for questions 3-6 and 9-14
- An average of the ratios is used as the final evaluation of the function structure.

This rubric allows the raters to objectively rate the function structure and provide a percent correction for each question and for the function structure as a whole.

6. Future Plans

- Conduct a study to determine inter rater agreement for the proposed evaluation rubric.
- Coduct a experimental function modeling activity with whiteboard capture system shown in figure 4.
- Explore problem statements for the experiment and select two problems
- Compile necessary material for conducting the supplementary study

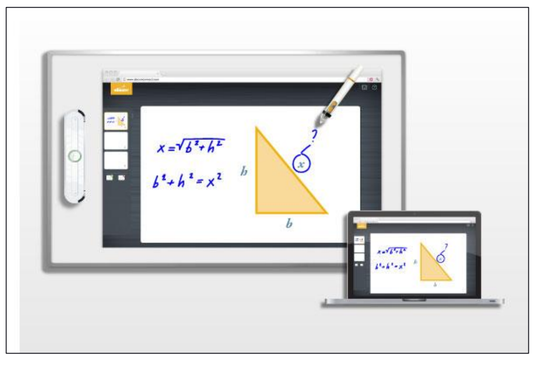

Figure 4: E-Beam Whiteboard Capture System

7. Conclusions

As much of the research remains to be done, it is not possible to make major conclusions. From the function structure evaluation study, it was observed that the evaluation rubric presented in [3] did not show strong agreement between raters. Additionally, it was noted that alternative methods for determining inter-rater agreement should be explored.

References

[1] M. a Kurfman, R. B. Stone, M. VanWie, K. L. Wood, and K. N. Otto, "Theoretical underpinnings of functional modeling: preliminary experimental studies," 12th Int. Conf. Des. Theory Methodol., 2000.
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