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# Effects of Seeding Function Structures on Modeling Behaviors

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- Background on Function Modeling
- Pilot Study
- Research questions
- Experiment design
- Comparison of experiment types
- Chaining pattern results
- Pause pattern results
- Conclusions
- Future Work
- References

- Tool used in conceptual design stage

- **Generative Design**

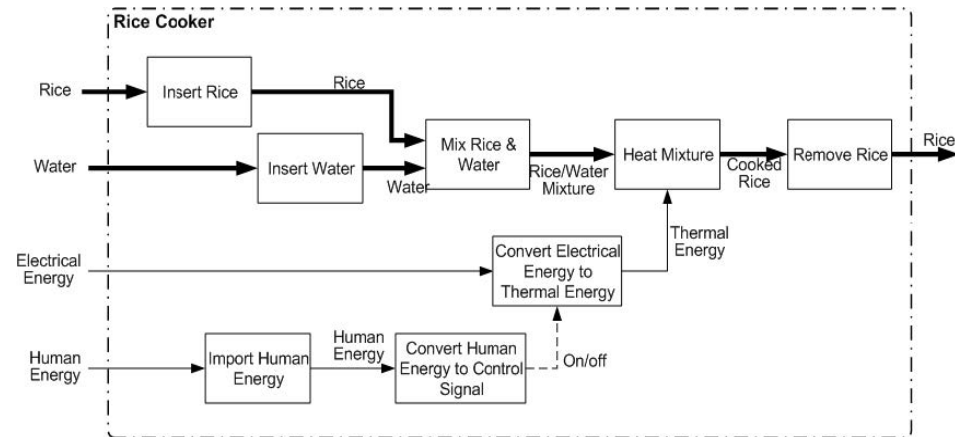
- Relate problem space to solution space
    - Place boundaries on the design space

- Reverse Engineering

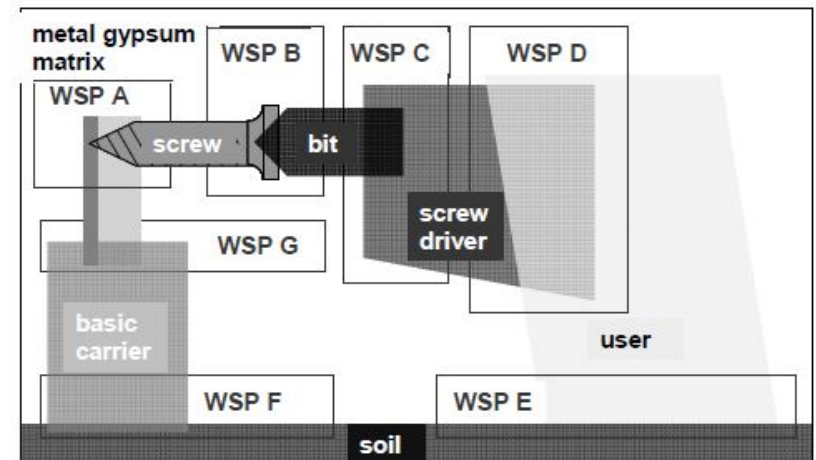
- Decompose product function
    - Identify excess in design
    - Trace product evolution

- Representations

- Function-Behavior-Structure Models
  - Function-Behavior-State Model
  - **Function Structure Models**
  - Structure-Behavior-Function Models
  - Contact and Channel Model



Function Structure for rice cooker

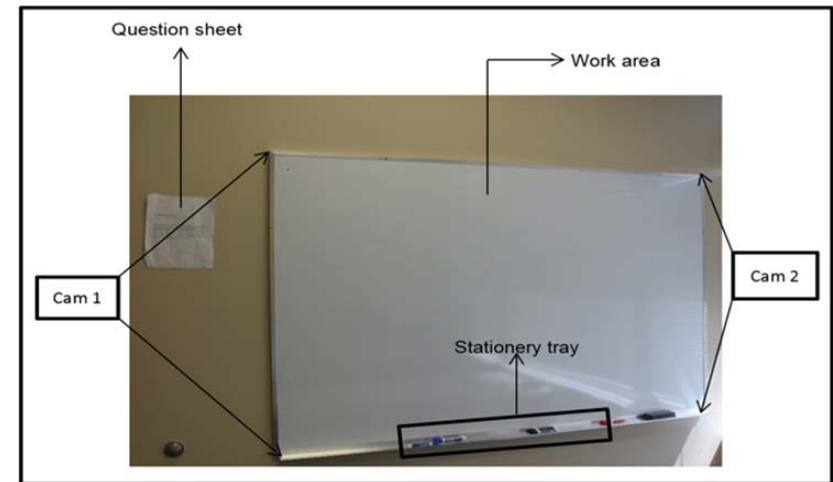


Working Surface Pair – WSP  
Channel and Support Structures – CSS = components

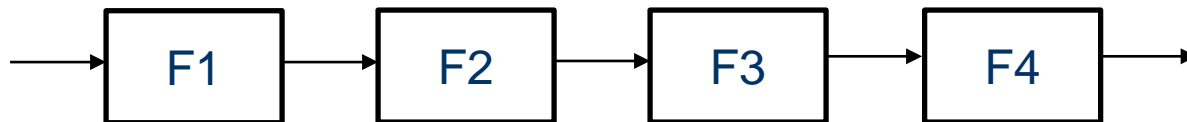
Contact and Channel Model

- Previous Research
  - Research focused on the model itself
    - Step-by-step model construction method
    - Formalization of vocabulary
    - Model evaluation
  - Research focused on use of the model
    - Generate solution concepts
    - A matrix representation to compare designs
  - Research focused on cognitive aspects
    - Analyzing modeling behaviors
- By understanding the modeling process
  - Educate better
  - Predict how the model is being constructed
  - Shorten modeling time
  - Explain the importance of function structures

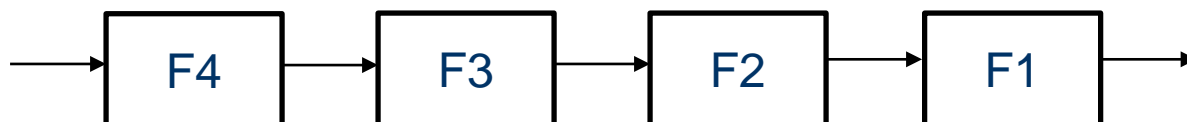
- Initial Protocol Study
  - 8 ME graduate students
  - Video recording of modeling activity
  - Video coding and Analysis
    - Add, delete, edit, and pauses
- Observations from initial protocol studies
  - Modeling patterns are likely to exist in designer behavior
    - Model chaining
      - Forward Chaining
      - Backward Chaining
      - Nucleation
    - Pause patterns
      - Pause Length and Frequency
    - Rate of model growth



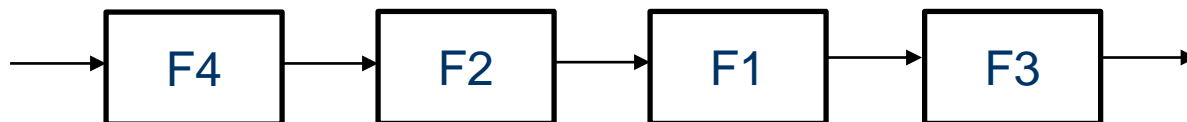
- Forward chaining



- Backward chaining



- Nucleation chaining

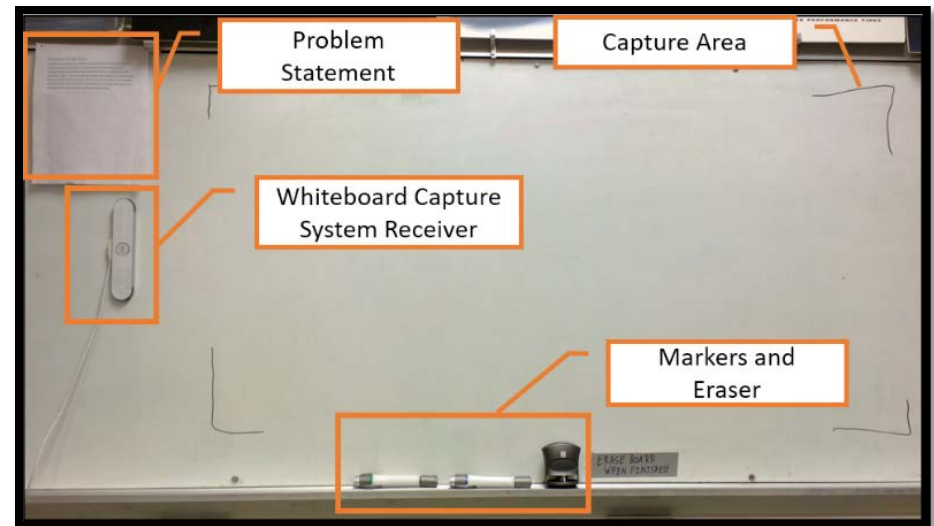


1. Are function structure models generated in a **designer study significantly different from** those generated in a **protocol study**?
2. Are function structure models generated using different **chaining method seeds significantly different**?
  - a) With respect to functions and flows added
  - b) With respect to model evaluations
  - c) With respect to model complexity
3. Can we **identify pause patterns in modeling behavior** when creating function models?
  - a) With respect to pause length and frequency
  - b) With respect to activity between pauses

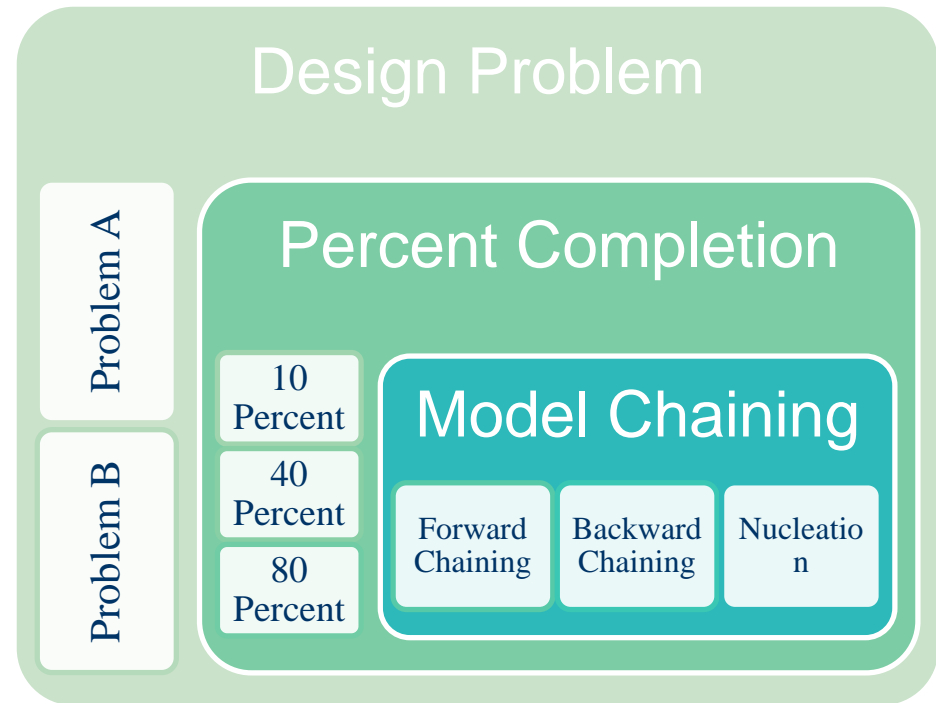
- Background on Function Modeling
- Pilot Study
- Research questions
- Research method selection
- **Experiment design**
  - Comparison of experiment types
  - Chaining pattern results
  - Pause pattern results
  - Conclusions
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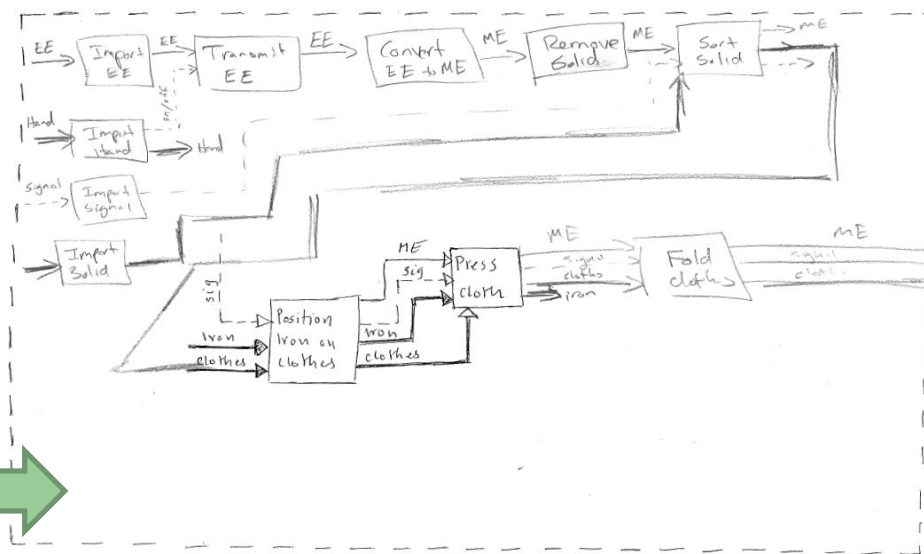
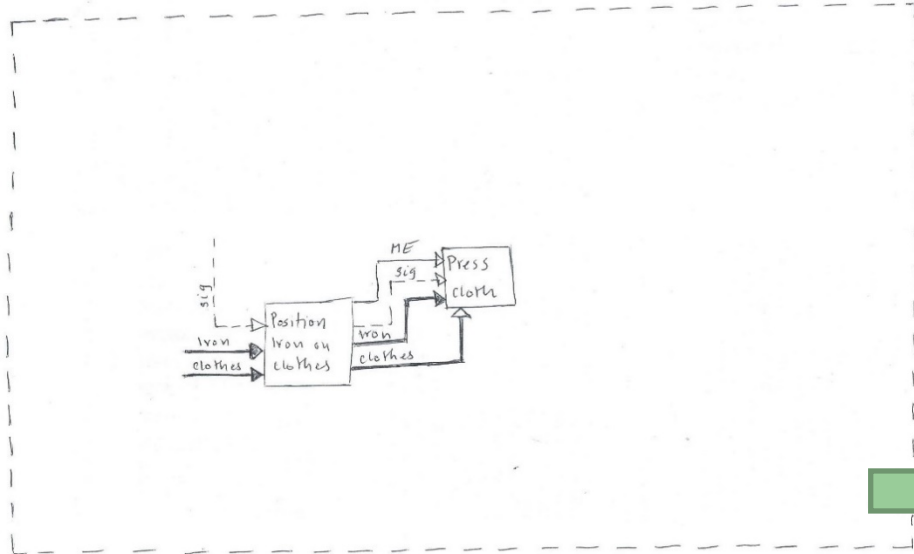
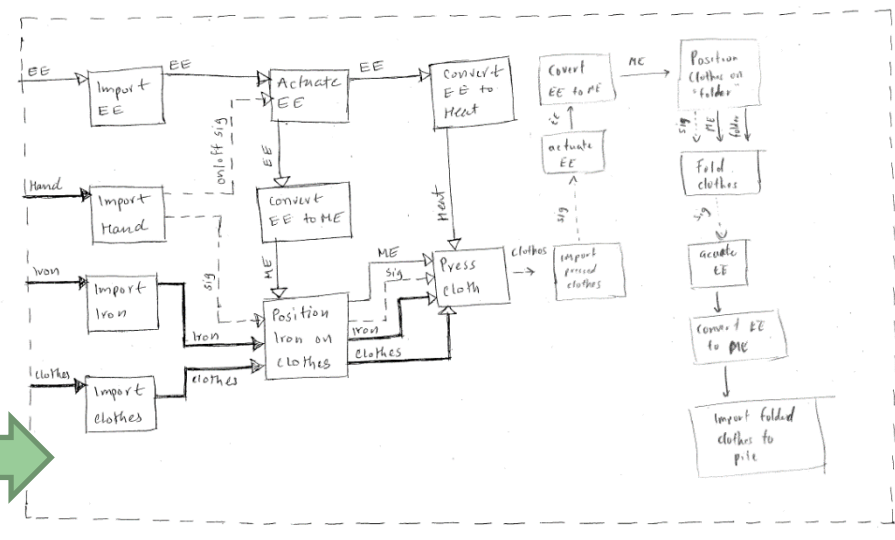
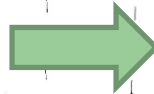
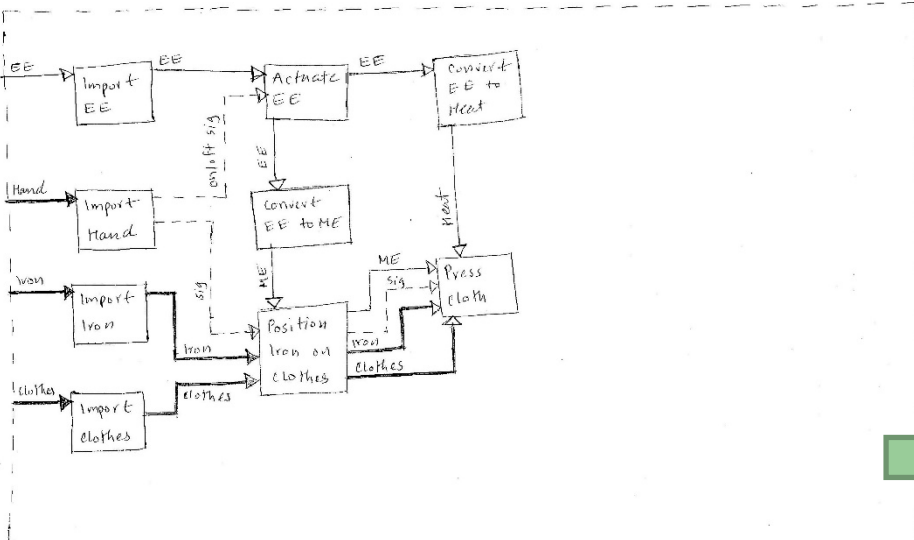


- Primary objective
  - Investigate differences between chaining methods
  - Effects of seeding with partially completed models
- Two part experiment
  - Part 1: Designer study
  - Part 2: Protocol study



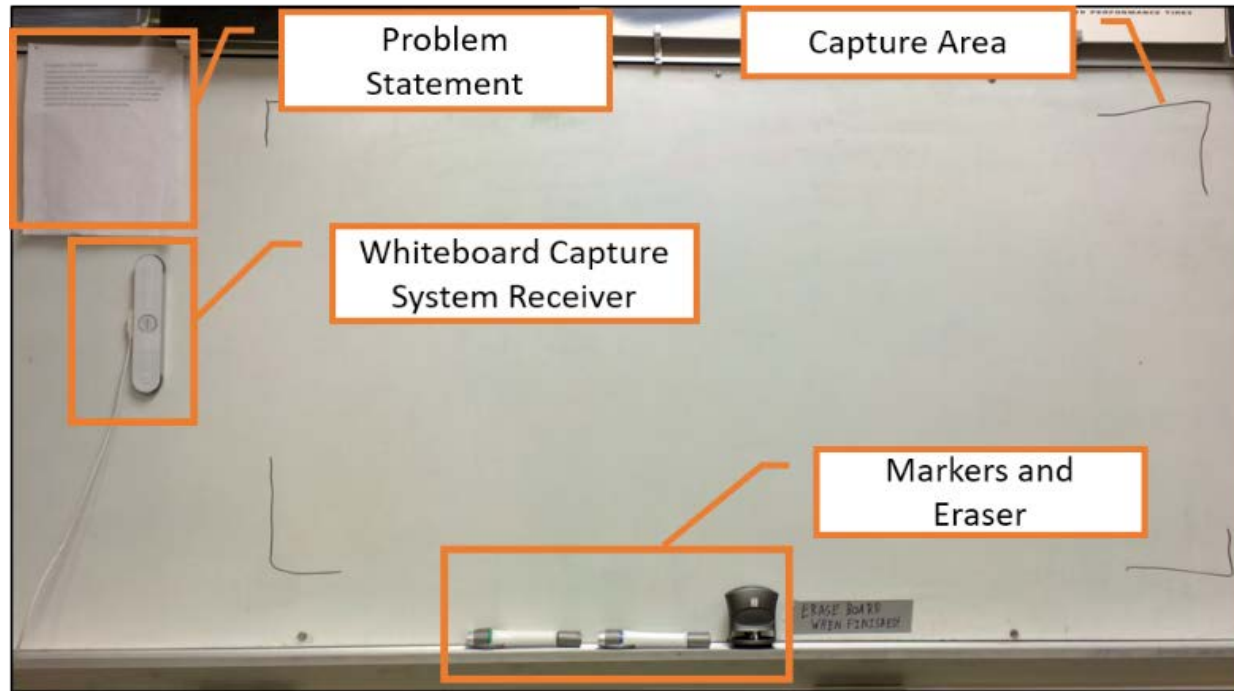
- Two design problems
  - Automatic folding and ironing machine
    - Used in the pilot study
    - Requires sorting, ironing, and folding
  - Automatic recycling sorter
    - Adapted from ASME Student Design Competition
    - Requires sorting, compressing, and storing





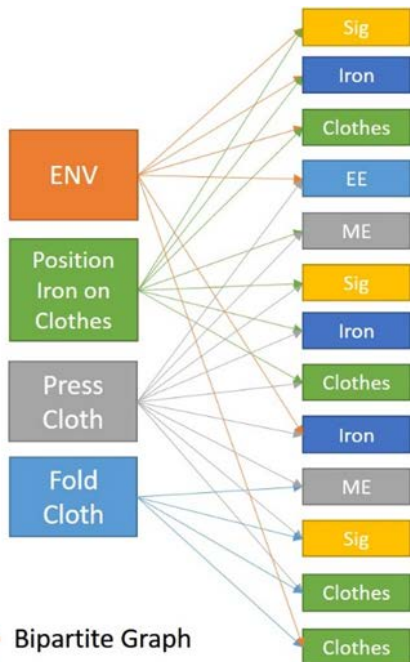
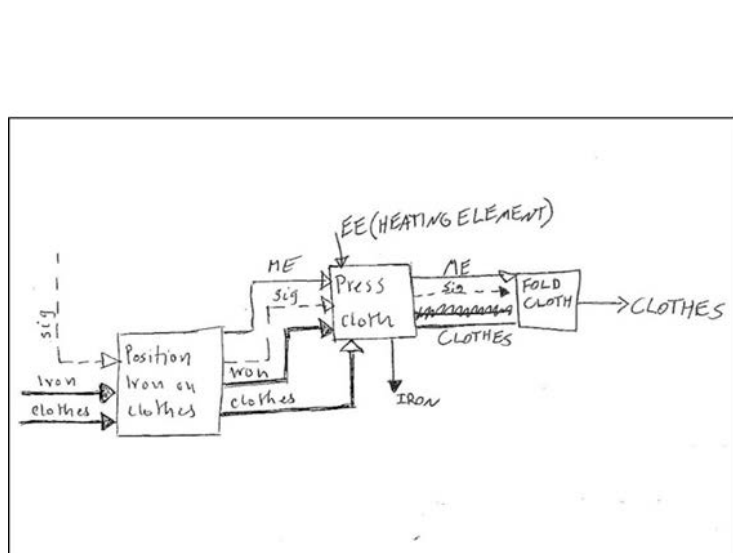
- 86 participants
  - 1<sup>st</sup> semester ME Senior Design students
- 2 models per participant
- Conducted as a class activity
- Mixed factorial experiment
  - Between subject replication
  - Within subject replication
- Experimental packet
  - Both design problems
  - Two different chaining method
  - Two different completion levels
- Final models collected





- Set in a closed meeting room
- Minimize distractions
- No time limits
  - 30 to 45 minutes expected
- Camera recording
- Whiteboard capture
- 22 students (ME senior design 1)
  - Familiar with function structures
  - Familiar with ironing and recycling
- Age group of 20 – 25 years
- Internship or Co-op experience

- Final function structures collected
- Protocol study video collected
- Function structure models analyzed for...
  - Increase in functions and flows
  - Change in model complexity
  - Rubric based evaluation
- Comparisons
  - Protocol study vs designer study
  - Chaining methods
- Videos analyzed for...
  - Pause lengths and frequency
  - Activity between pauses



Function Structure → Bipartite Graph

Euclidian      Chebychev

Cosine          Hamming

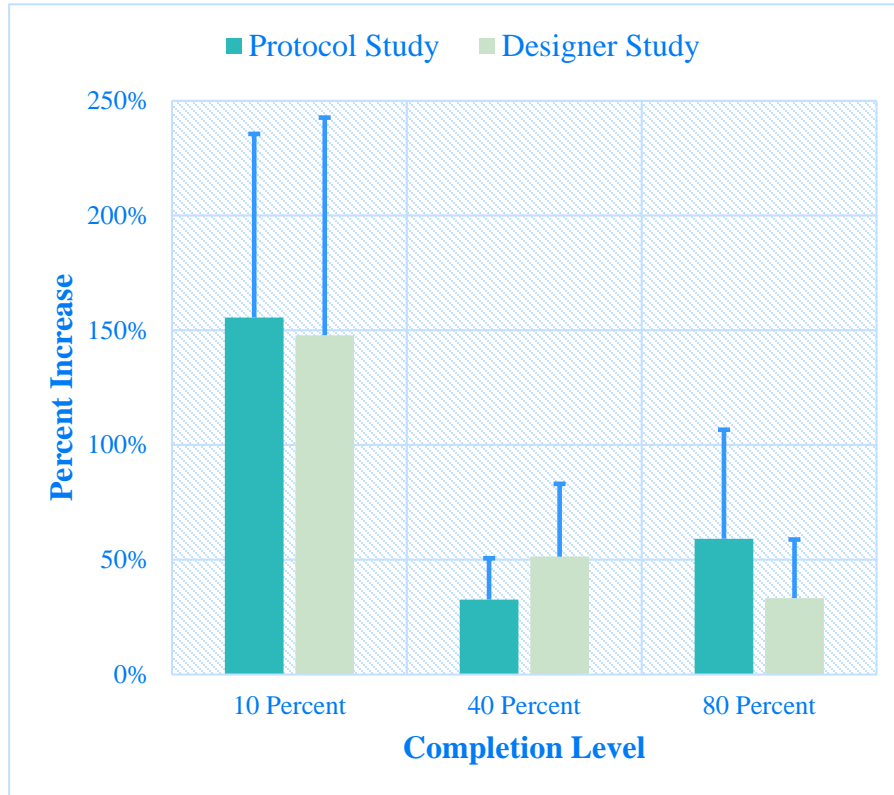
**Complexity Distances**

Class	Type	Metric
Size	Dimension	Elements
		Relations
	Connection	DOF
		Conn
Inter-connection	Shortest Path	Sum
		Max
		Mean
	Flow Rate	Density
		Sum
		Max
Centrality	Between-ness	Mean
		Density
		Sum
	Clustering Coefficient	Max
		Mean
		Density
Decomposition	Ameri-Summers	
	Core Numbers In	Sum
		Max
		Mean
	Core Numbers Out	Density
		Sum
Max		
	Mean	
	Density	

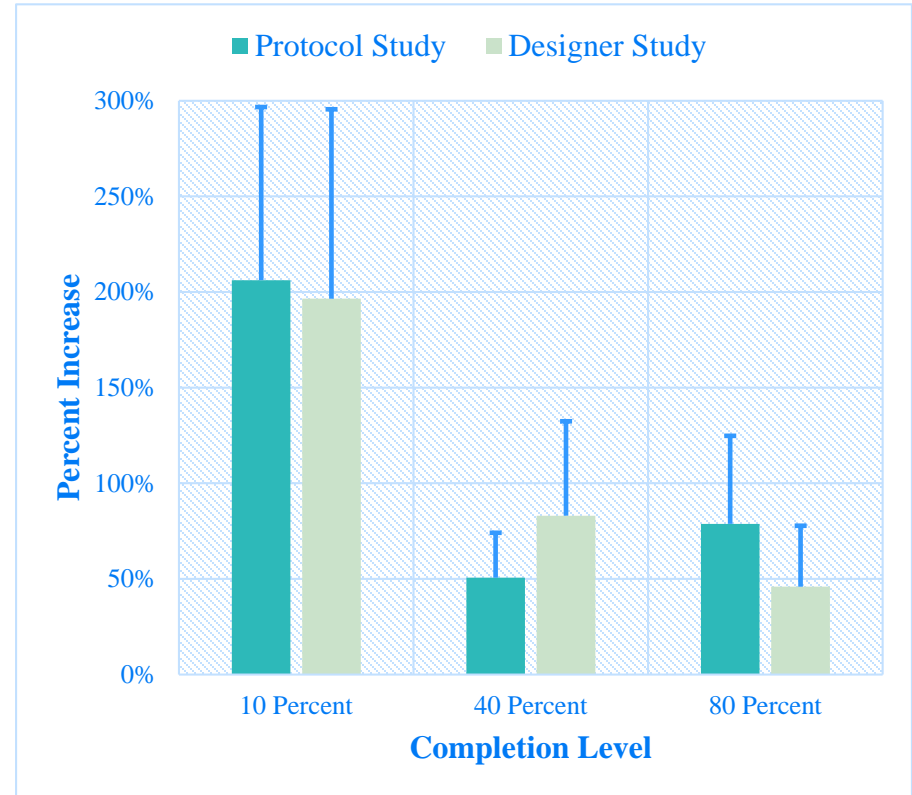
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## Increase in Functions

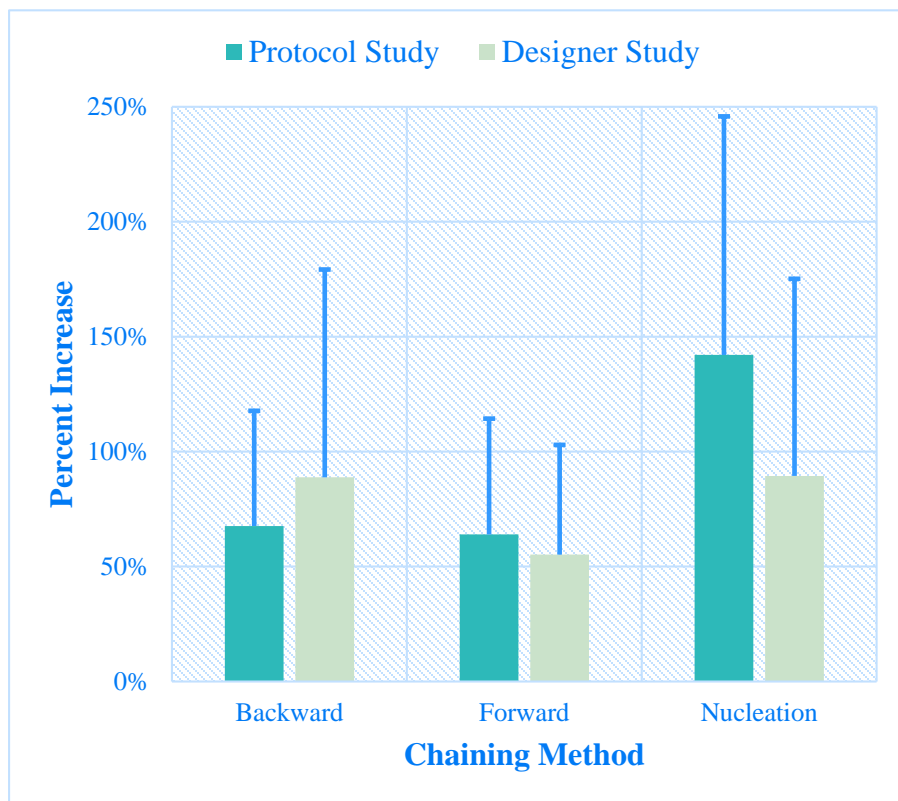


## Increase in Flows

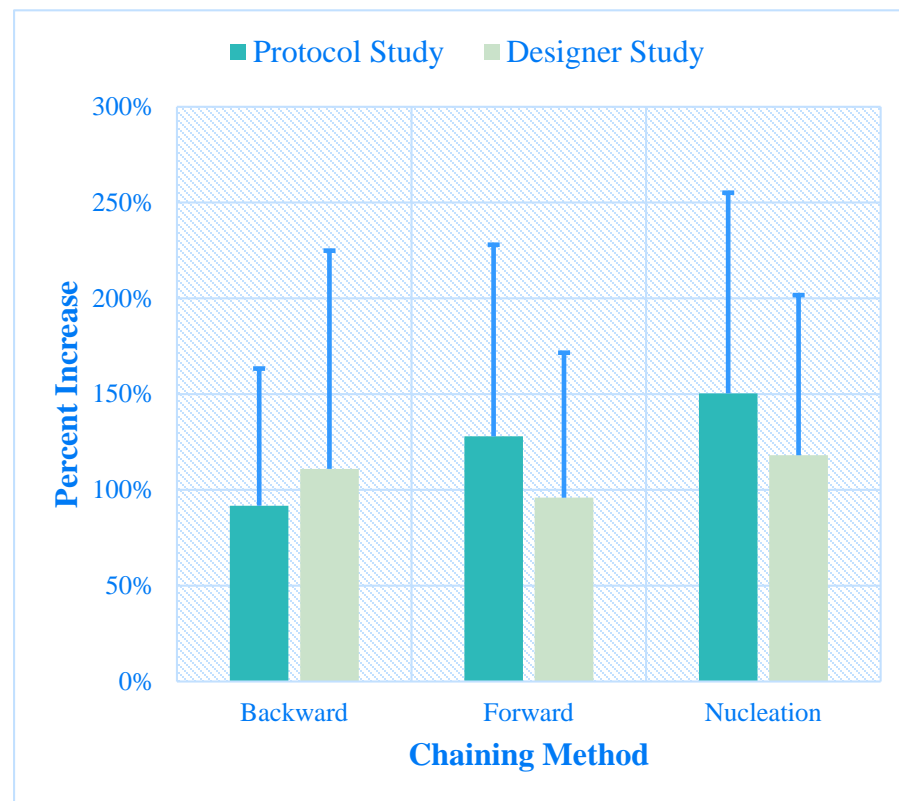


40% complete significantly different for flows

## Increase in Functions



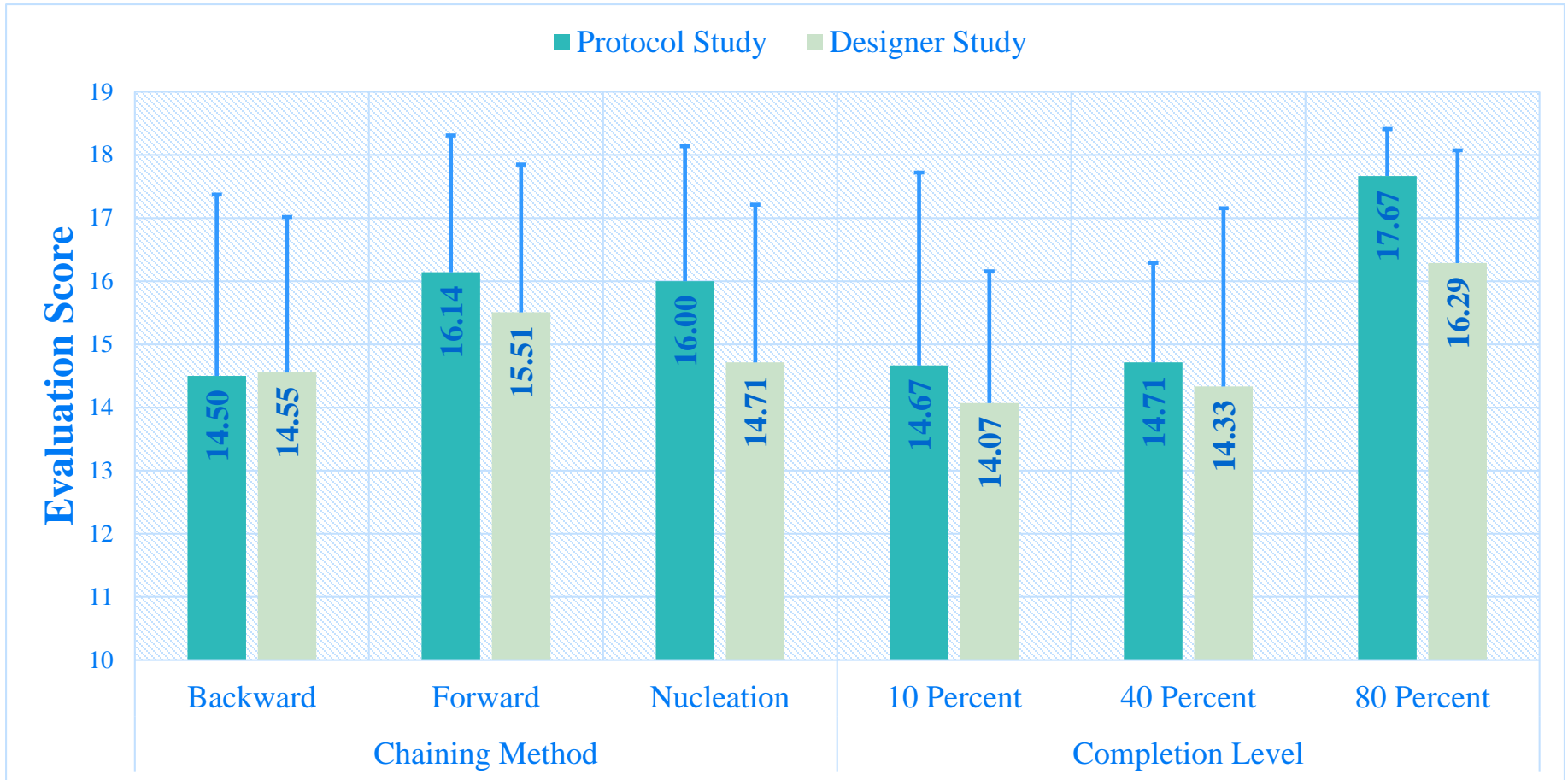
## Increase in Flows



No significant differences were found

- No significant difference for Euclidian distance
- Suggestive differences for 40% (Chebychev) and 80% (Hamming)
- Significant different found for Backward chaining (Hamming), and 80% (Cosine)

	Case	p-value	Case	p-value
Chebychev	Backward	0.630	10 Percent	0.710
	Forward	0.867	40 Percent	0.084
	Nucleation	0.483	80 Percent	0.988
Cosine	Backward	0.968	10 Percent	0.880
	Forward	0.744	40 Percent	0.158
	Nucleation	0.346	80 Percent	0.034
Euclidian	Backward	0.605	10 Percent	0.717
	Forward	0.868	40 Percent	0.069
	Nucleation	0.656	80 Percent	0.912
Hamming	Backward	0.066	10 Percent	0.895
	Forward	0.473	40 Percent	0.474
	Nucleation	0.742	80 Percent	0.086

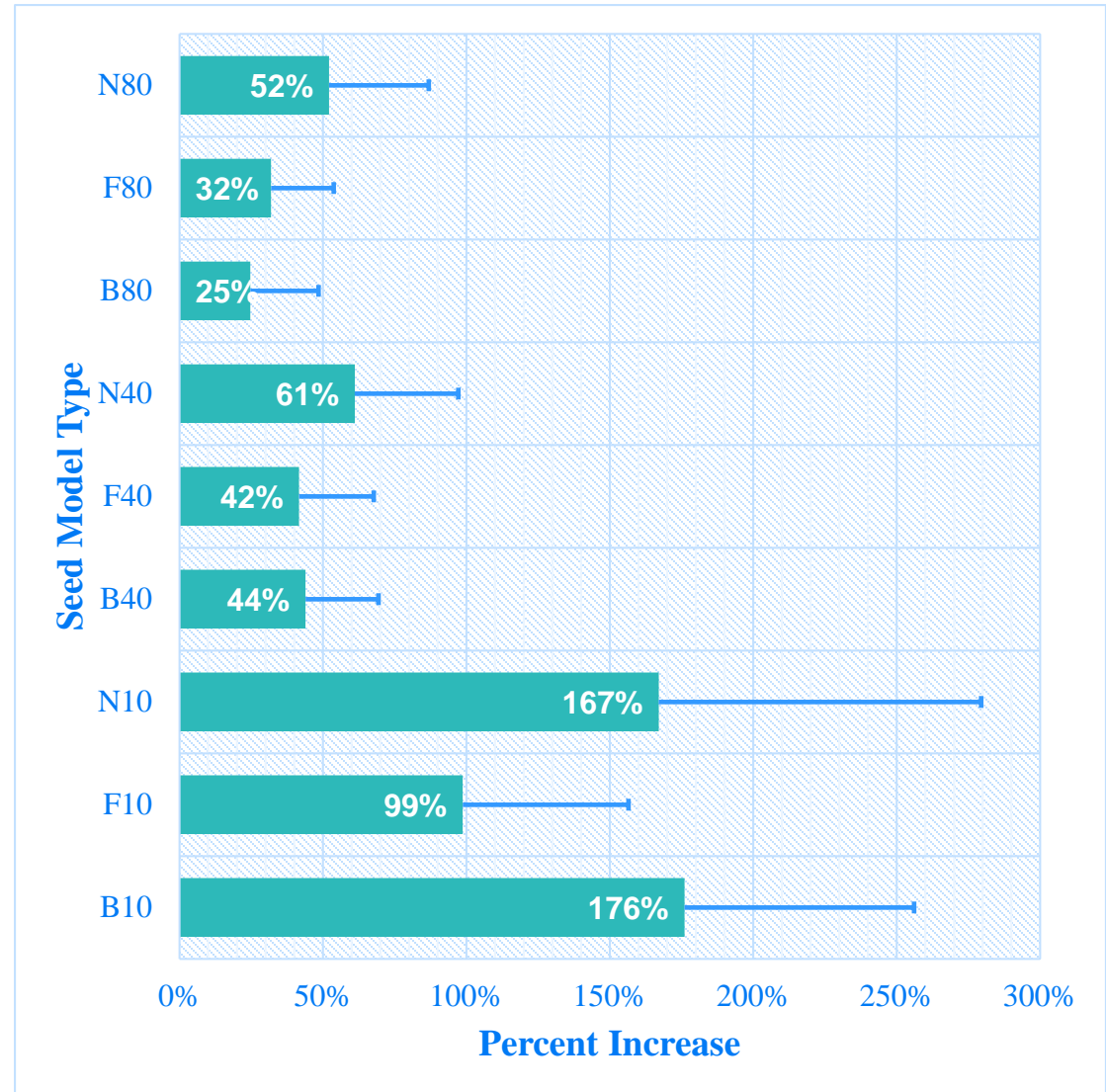


80% complete models significantly different

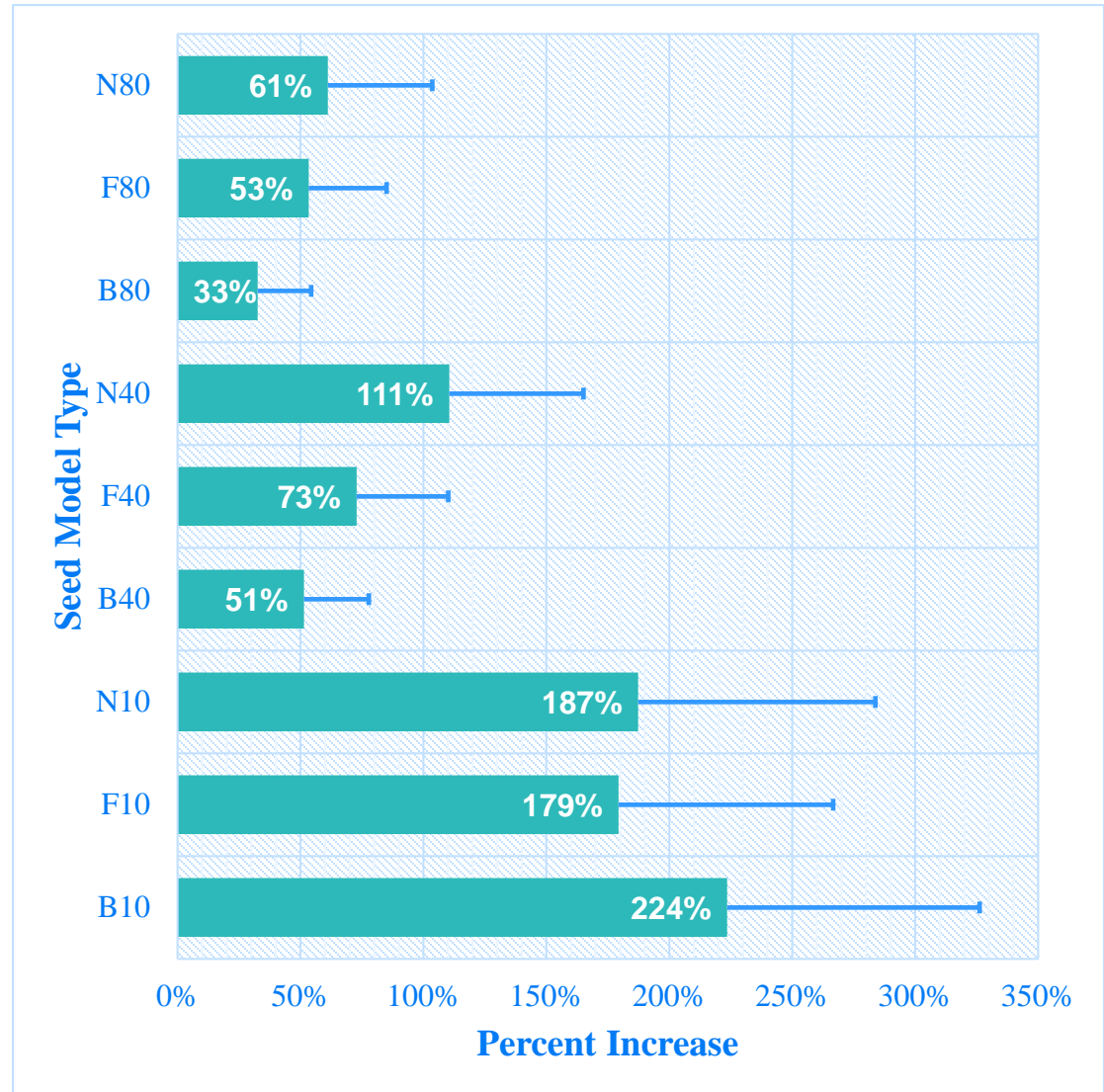
- Increase in functions and flows is comparable
  - Except flows in 40% complete models
- Change in model complexity is comparable
  - Except 80% models with cosine distance
  - Except backward chaining modes with hamming distance
- Rubric based evaluation scores are comparable
  - Except 80% complete models

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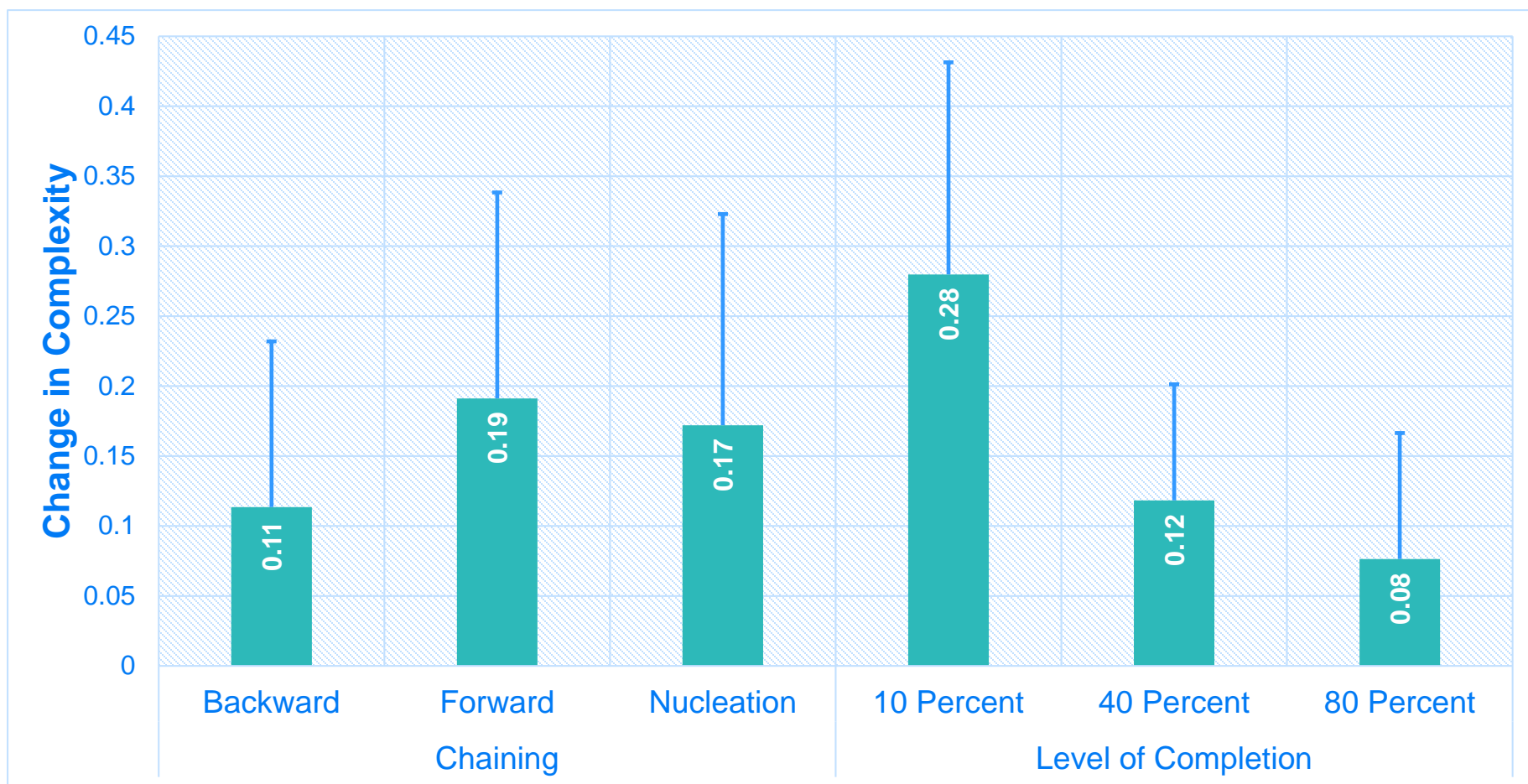
- 10% models
  - Backward and nucleation similar
  - Larger variance for nucleation
- 40% models
  - Backward and forward similar
  - Less variance compared to 10% models
- 80% models
  - Nucleation significantly more than backward and forward



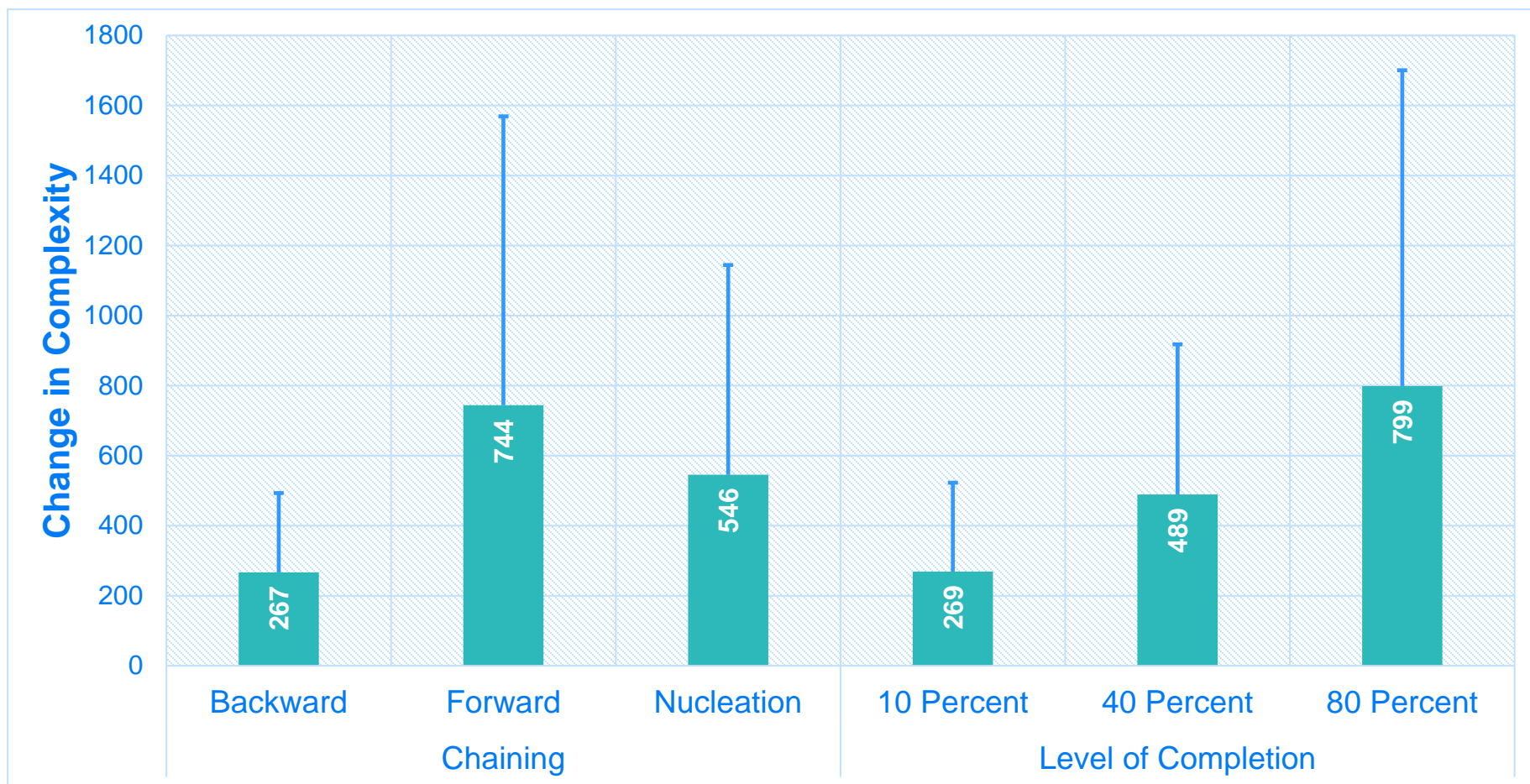
- 10% models
  - Forward and nucleation similar
  - High variances
- Similar trends for 40% and 80% models
  - Increasing order of backward, forward, nucleation.
- Generally similar to functions



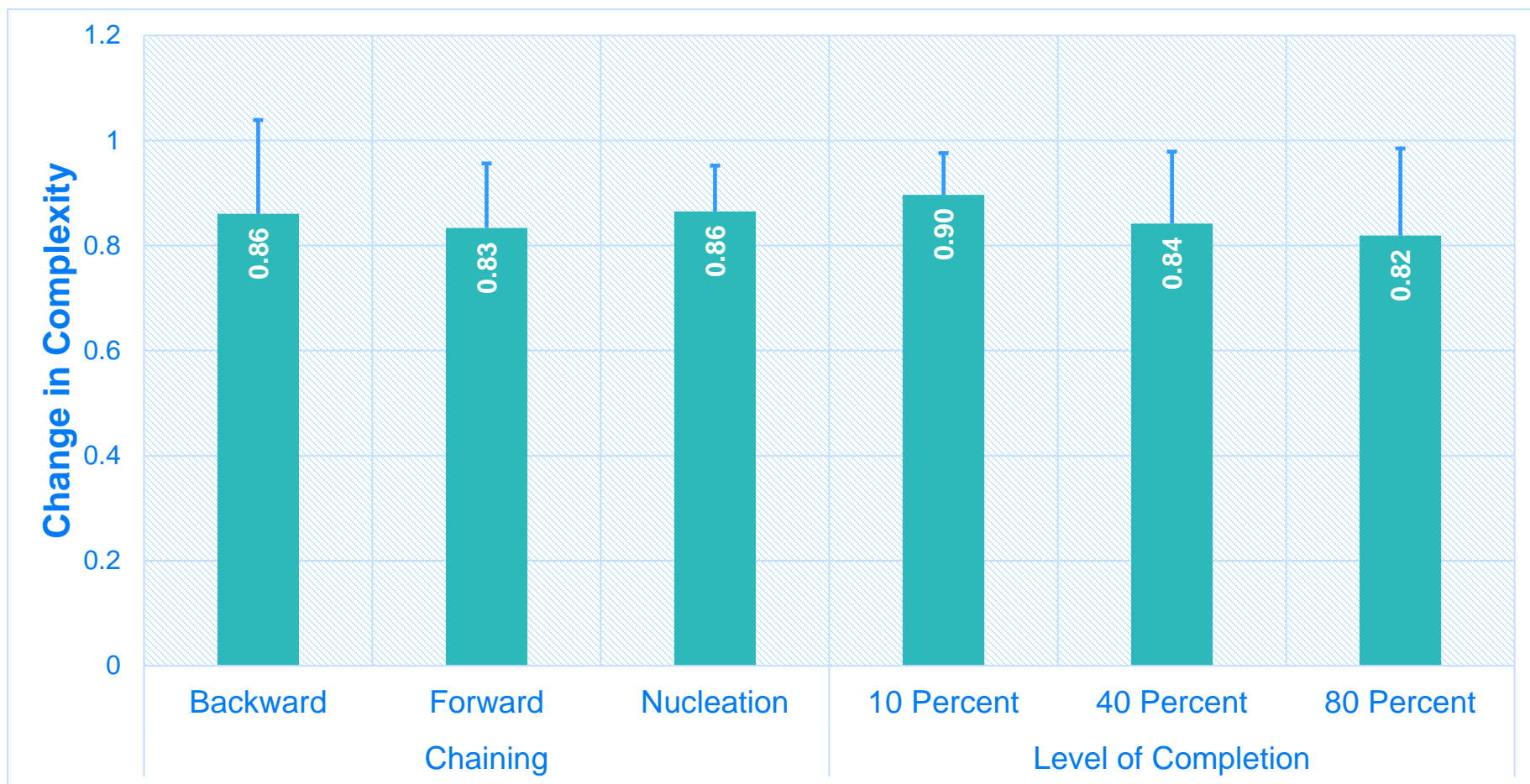




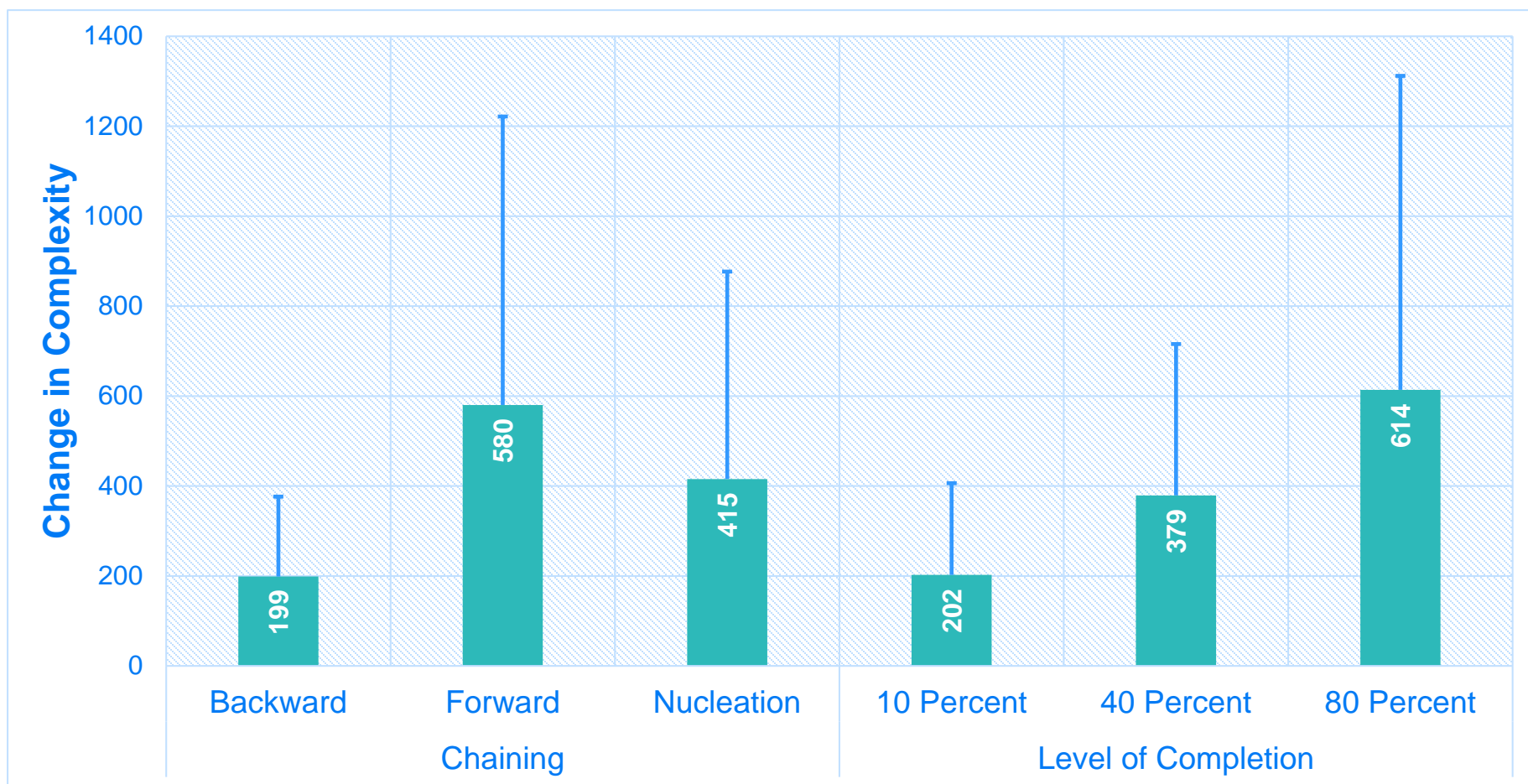
Forward and nucleation models found to be similar



Forward and nucleation models found to be similar

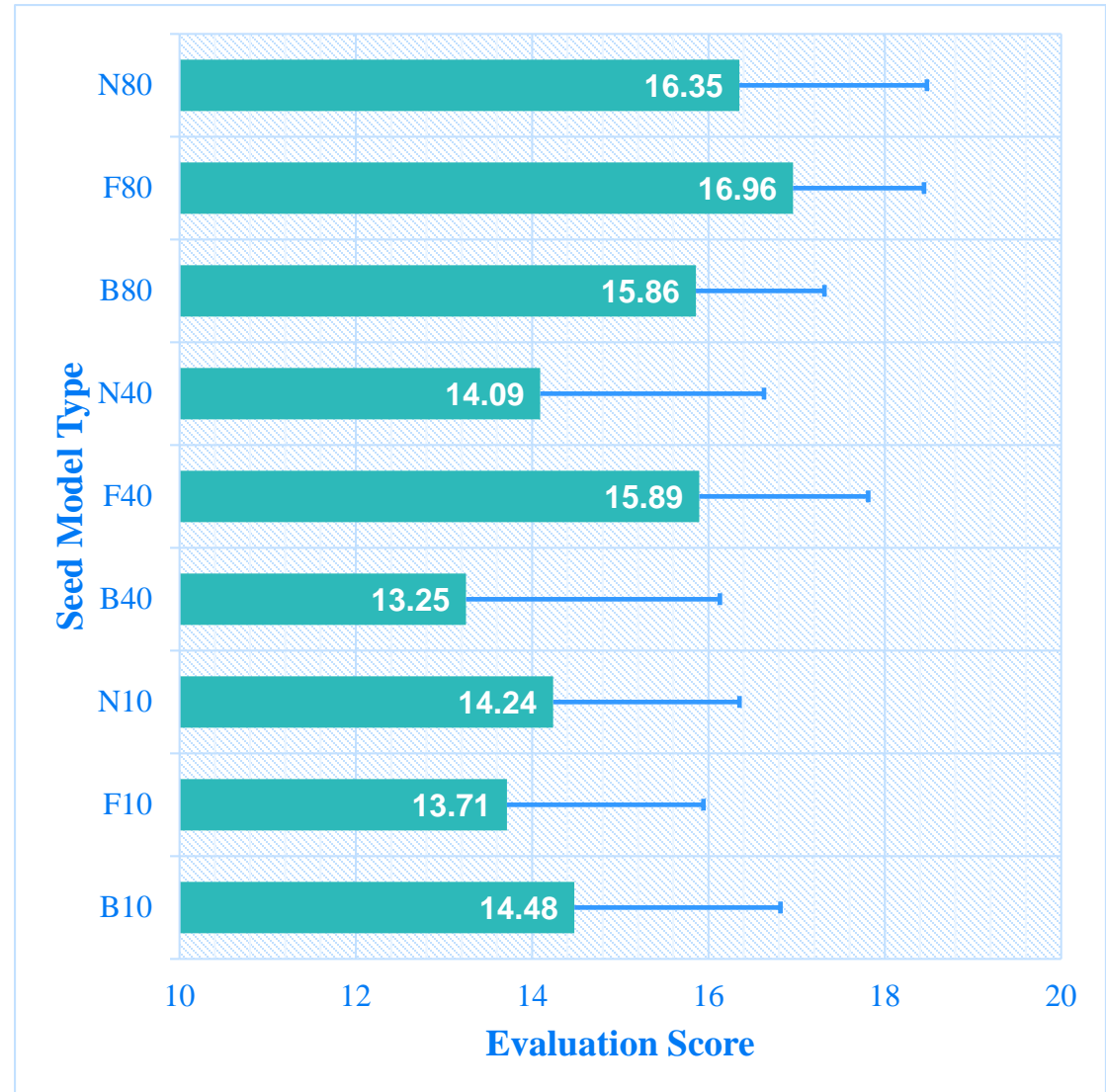


10% models different from all other models



Forward and nucleation models found to be similar

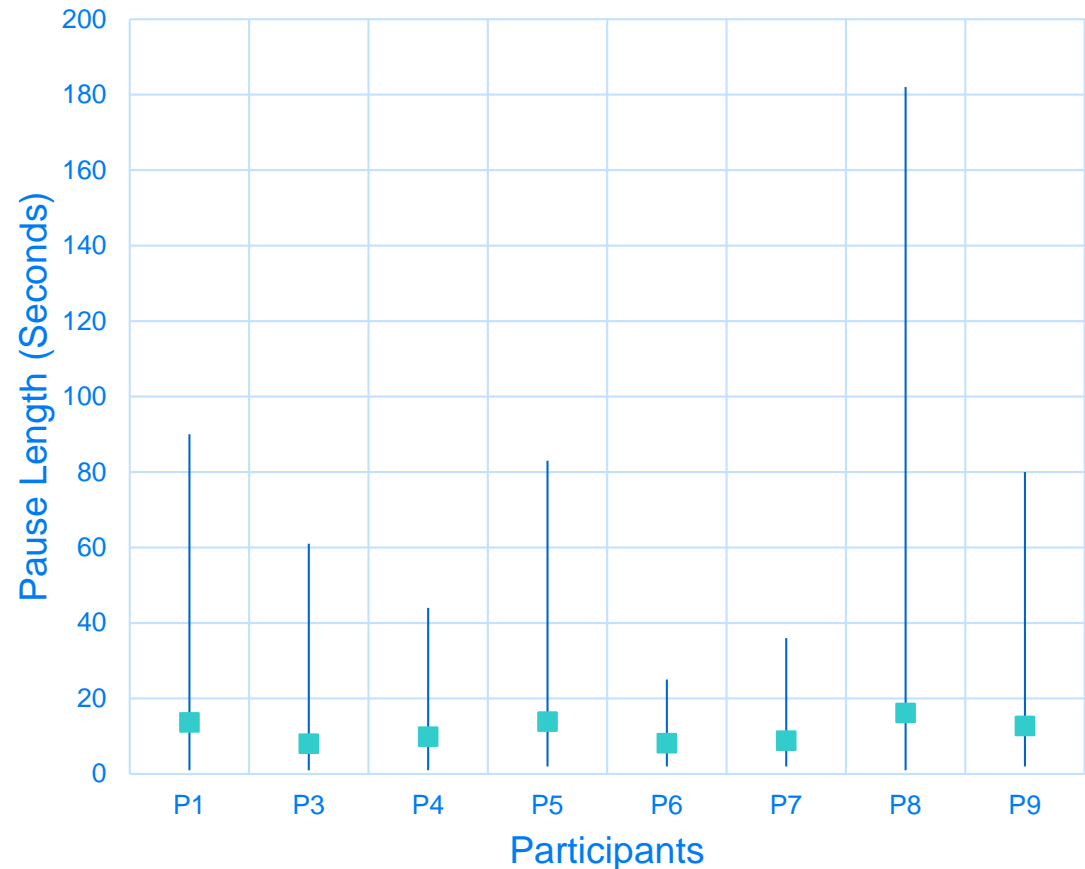
- 10% models significantly different from F40, and all 80% models
- Backward chaining and nucleation found to be similar



- Nucleation shows higher increase in functions and flows
- Nucleation showed comparable change in model complexity
- Forward chaining generates better evaluation scores

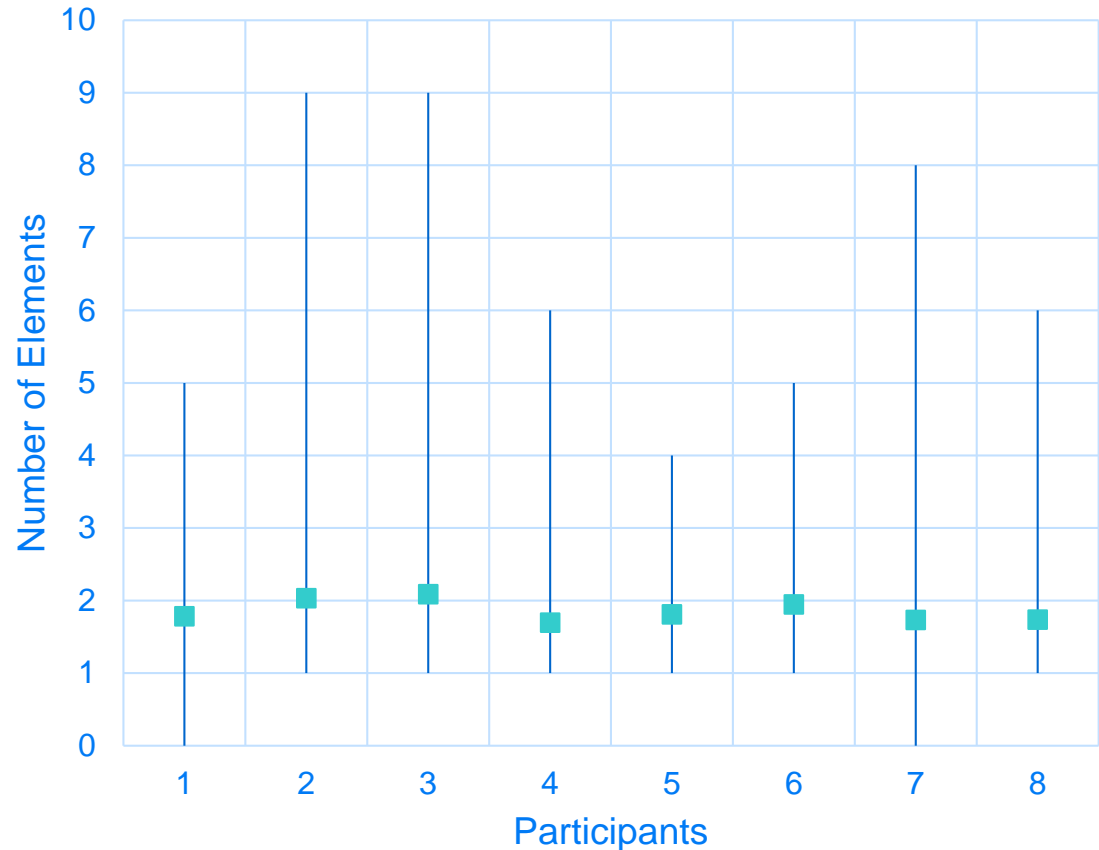
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- Average pause length less than 20 seconds for all participants
- P8 has the highest range, 181 seconds
- P6 has the smallest range, 23 seconds





- Average number of elements after pause is ~2
- Maximum number of elements after pause is 9



- No significant differences between studies
  - By chaining methods
    - No significant difference in function or flow increase
  - By seed model completion
    - No difference in function increase
    - 40% complete found different for flow increase
  - Similar based on model evaluation scores
- Comparison of chaining methods
  - Backward chaining and nucleation found to be similar
    - 10% completion functions
    - Model evaluations
  - Nucleation overall yields more additions to the model
  - Forward chaining yields more complete models

- Analysis of Function and Flow Labels
  - How similar are the function labels between different chaining methods?
  - How similar are the flow labels between different chaining methods?
  - Can the Functional Basis Vocabulary be used to compare the chaining methods?
  - How different are the chaining methods with respect to the number of distinct function labels and flow labels?
- Analysis of Change in Model Complexity
  - How do individual complexity metrics change from given model to final model?
  - How does the change in individual complexity metrics differ between the three levels of completion?
  - How are the individual complexity metrics different between the chaining methods?
  - How does the change in individual complexity metrics differ between the chaining methods?

- Evaluation of Function Structure Models
  - Question by Question Evaluation
  - Alternative evaluation methods
  - Correlation of evaluation of model performance
- Evaluation of Modeling Activity
  - What patterns exist in modeling activity with respect to pause length and frequency?
  - What patterns exist in modeling activity with respect to the type of activity followed by a pause?
  - What patterns exist in modeling activity with respect to the number of elements added, deleted, or edited after a pause?
  - What patterns exist in modeling activity with respect to the clustering of elements between pauses?
  - How does presence of a seed model affect pause patterns?
  - How are pause patterns different based on the type of chaining method used for the seed model?

# QUESTIONS?

# BACKUP SLIDES

## Automatic Clothes Ironing

Design an automatic clothes-ironing machine for use in hotels. The purpose of the device is to press wrinkled clothes as obtained from clothes dryers and fold them suitably for the garment type. You are free to choose the degree of automation. At this stage of the project, there is no restriction on the types and quantity of resources consumed or emitted. However, an estimated 5 minutes per garment is desirable.

## Automatic Recycling Sorter

Design an automatic recycling machine for household use. The device should sort plastic bottles, glass containers, aluminum cans, and tin cans. The sorted materials should be compressed and stored in separate containers. The amount of resources consumed by the device and the amount of space occupied are not limited. However, an estimated 15 seconds of recycling time per item is desirable.

- Two design problems selected to be similar
  - Similar word count (70 and 61)
  - Similar number of functions (3 each)
- Similar participant response
  - No significant difference
    - Functions and Flows

	Variable 1	Variable 2
Mean	0.835748	0.713711
Variance	0.829389	0.406609
Observations	86	86
Hypothesized Mean Difference	0	
df	152	
t Stat	1.017962	
P(T<=t) one-tail	0.155157	
t Critical one-tail	1.65494	
P(T<=t) two-tail	0.310314	
t Critical two-tail	1.975694	



- Interdependence occurs in groups
  - Concept from organizational psychology
  - Stems from differences in perception of concepts
- Pooled interdependence
  - Individual activity
  - End product is an accumulation
- Sequential interdependence
  - Individuals modify partially completed work
  - Work is completed in a sequence
  - Examples: C-Sketch, Method 6-3-5
- Reciprocal Interdependence
  - Individuals exchange work within the group
  - Work is completed after iterations
  - Example: Gallery Sketching

- Model contains a black box?
- Black box contains input and output flows?
- Are the input and output flows in the black box appropriate?
- Does the black box represent flow conservation?
- Do inputs from the black box match functional model inputs?
- Do outputs from the black box match functional model outputs?
- Does the functional transformation described by the black box represent a plausible overall system functionality?
- Does the black box function–flow pair take the general form a verb/noun pair?
- Do the function–flow pairs in the functional model overall represent a plausible view of the product?
- Do the function–flow pairs in the functional model take the general form of a verb/noun pair?
- Is the functional model free of nonsensical functions?
- Is the functional model free of nonsensical flows?
- Is the model free of instances where the system acts on the system?
- Is flow directionality consistent with the transformation in the functions?
- Are flows conserved across function transformations?
- Are flow paths appropriate for product representation?
- Does the functional model represent flow conservation?
- Are the proper energy, material, and signal flow arrow conventions followed?