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# High School Students' Perspectives on Mathematical Modeling in the Engineering Design Process (RTP)

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# Background[1]

Engineering for US All (e4usa) is an NSF-funded program that offers pre-college engineering **curriculum**, **professional development** for teachers, and conducts **research** in engineering education research (EER). To date, e4usa involves 91 participating high schools with over 7,500 students.

| 7500+ | 25 | 91 |
|---|---|---|
| STUDENTS | U.S. STATES AND TERRITORIES | HIGH SCHOOLS AS PARTNERS |

# Background[2]

## 1 e4usa curriculum

- Unit 1 - Engineering is Everywhere
- Unit 2 - Engineering is Creative
- Unit 3 - Engineering is Human-Centered
- Unit 4 - Engineering is Responsive
- Unit 5 - Engineering is Intentional
- Unit 6 - Engineering is Iterative
- Unit 7 - Engineering is Personal
- Unit 8 - Engineering is Reflective
- Unit - Meet the Engineer

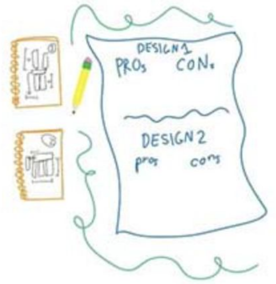
## 2 Unit 2 Water Filter

Curriculum in Unit 2

- Engineering is Creative - Unit 2
- 2.1 Introduction to Teaming
  - 2.1.1 Rain Shelter Design
- 2.2 Community Based Problems
  - 1.1.2 Think-Pair-Share
  - 2.2.1 Potable Water in the Community
- 2.3 Introduction to the Engineering Design Process
  - 2.3.1 Engineering an Engineering Design Process
  - 2.3.2 [CAD] Set Up Your CAD Workspace
- 2.4 Problem Definition
  - 2.4.1 Personal Potable Water Device Problem
  - 2.4.2 Research the Science
- 2.5 Ideation
  - 2.5.1 Brainstorming
  - 2.5.2 [CAD] Basic Sketching in

## 3 Lesson 2.6 MATLAB

### 2.6 Design Selection




Weighing the pros and cons of multiple ideas helps engineers select the best design
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#### Purpose/Summary

When engineers are brainstorming ideas for a design, they will likely come up with multiple solutions that need to be narrowed down. In this lesson and activity, students will come together as a whole class and use a shared set of criteria and a common, agreed upon scoring system to make a decision on the design of their personal water device.
*This engineering curriculum aligns to Next Generation Science Standards (NGSS).*

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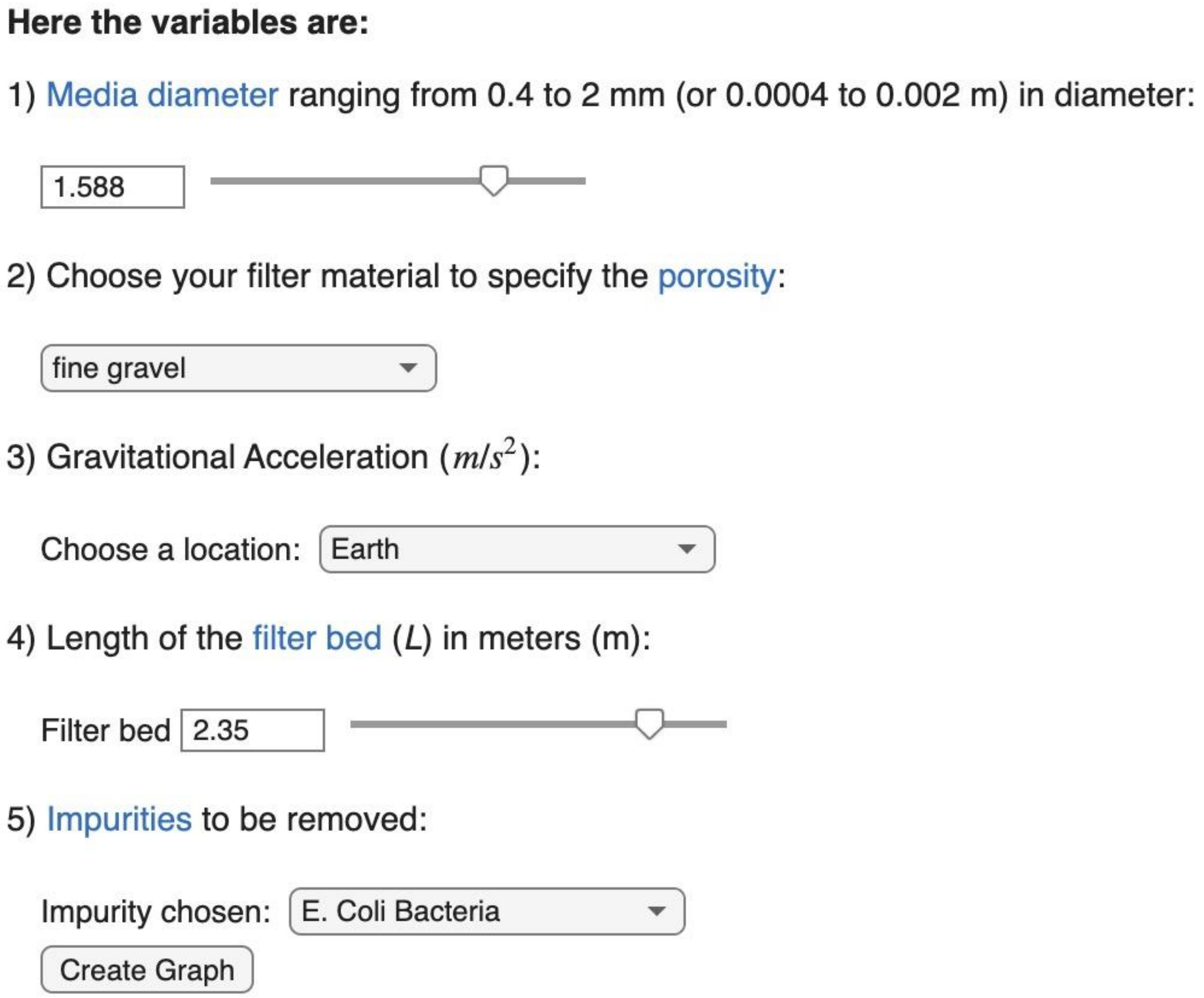
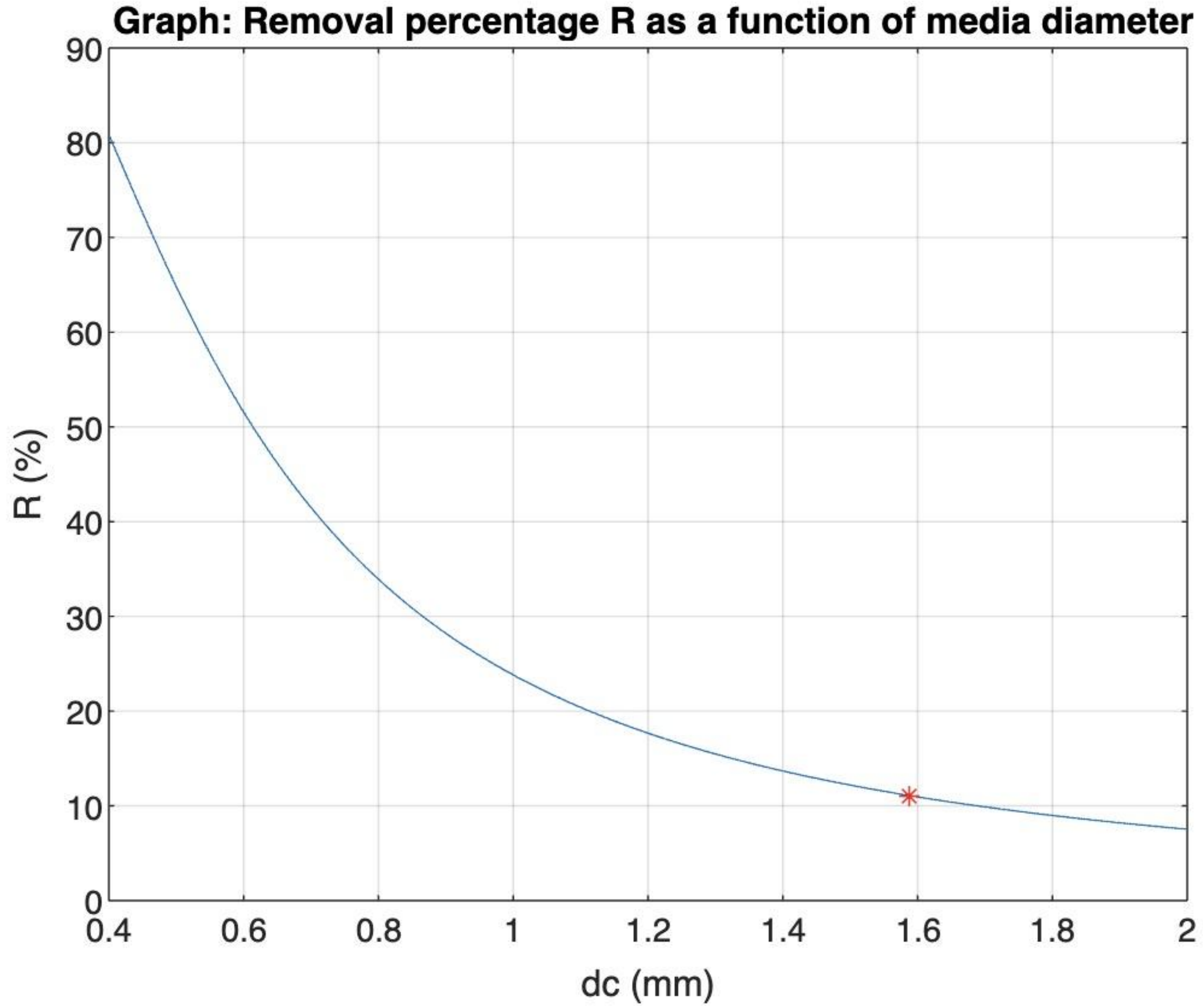
# Background

## MATLAB: User friendly interface



# Background

## [MATLAB](): "Hide code" vs "show code"

**Here the variables are:**

1) Media diameter ranging from 0.4 to 2 mm (or 0.0004 to 0.002 m) in diameter:

1.588

2) Choose your filter material to specify the porosity:

fine gravel

3) Gravitational Acceleration $(m/s^2)$:

Choose a location: Earth

4) Length of the filter bed ($L$) in meters (m):

Filter bed 2.35

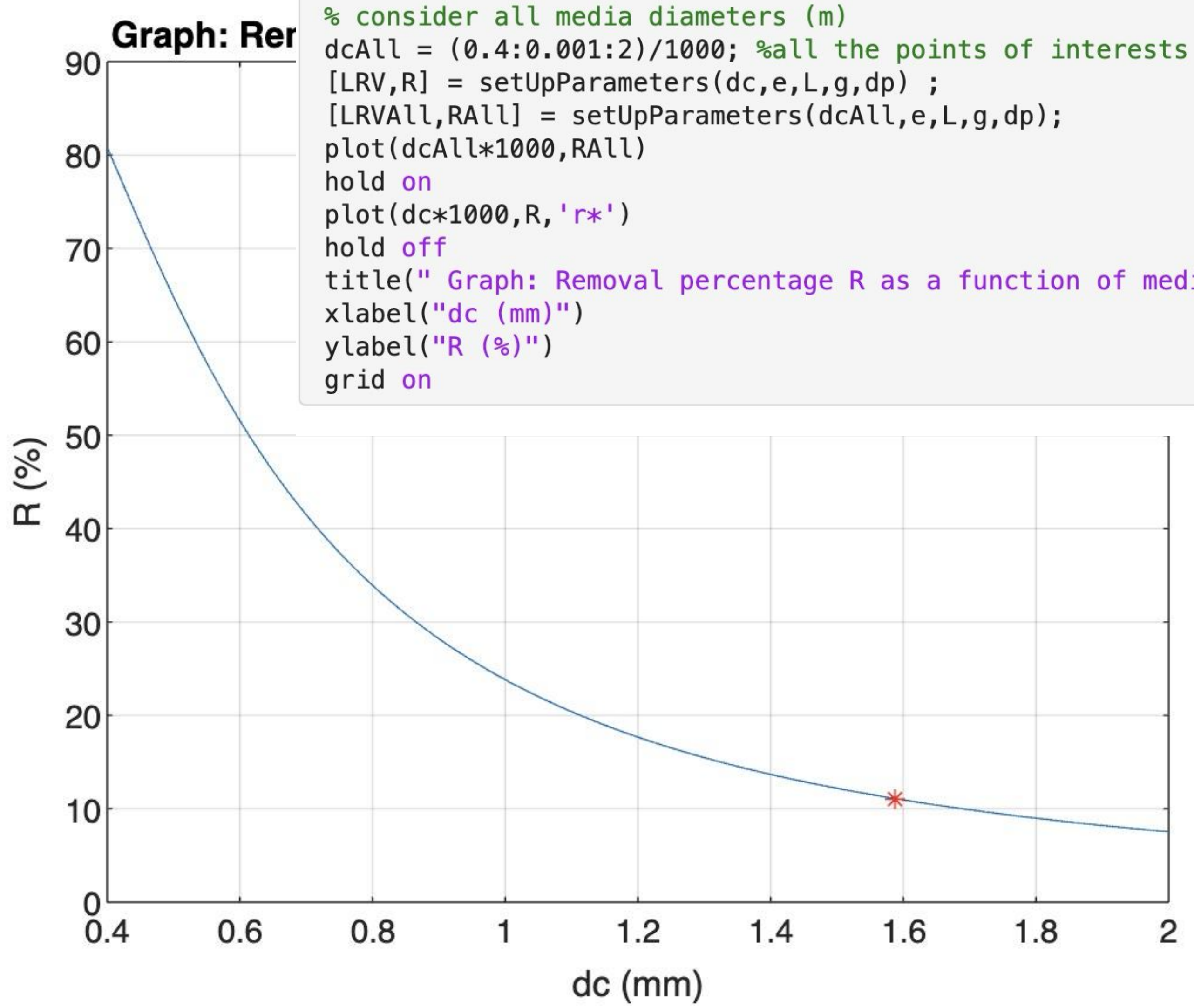
5) Impurities to be removed:

Impurity chosen: E. Coli Bacteria

Create Graph

**Graph Note:** This performance curve shows the percentage of the impurities removed out of the water (y-axis) as a function of the media diameter (x-axis). The higher the removal percentage, the higher the water purity. The red dot reflects the media diameter you have chosen on that performance curve. In the case of the example given earlier, the %R is about 10% at a media diameter of about 0.4mm.

```
% consider all media diameters (m)
dcAll = (0.4:0.001:2)/1000; %all the points of interests define the size of the matrix
[LRV,R] = setUpParameters(dc,e,L,g,dp) ;
[LRVAll,RAll] = setUpParameters(dcAll,e,L,g,dp);
plot(dcAll*1000,RAll)
hold on
plot(dc*1000,R,'r*')
hold off
title(" Graph: Removal percentage R as a function of media diameter")
xlabel("dc (mm)")
ylabel("R (%)")
grid on
```



# Research Questions

RQ1: How has MATLAB enabled student engagement in subsequent design activities, and to what extent did it enrich their decision-making processes?

*What in MATLAB helps?*

RQ2: What challenges did students face while using the MATLAB design tool, and what improvement could be made to better its effectiveness and user experience in an educational setting?

*What to improve?*

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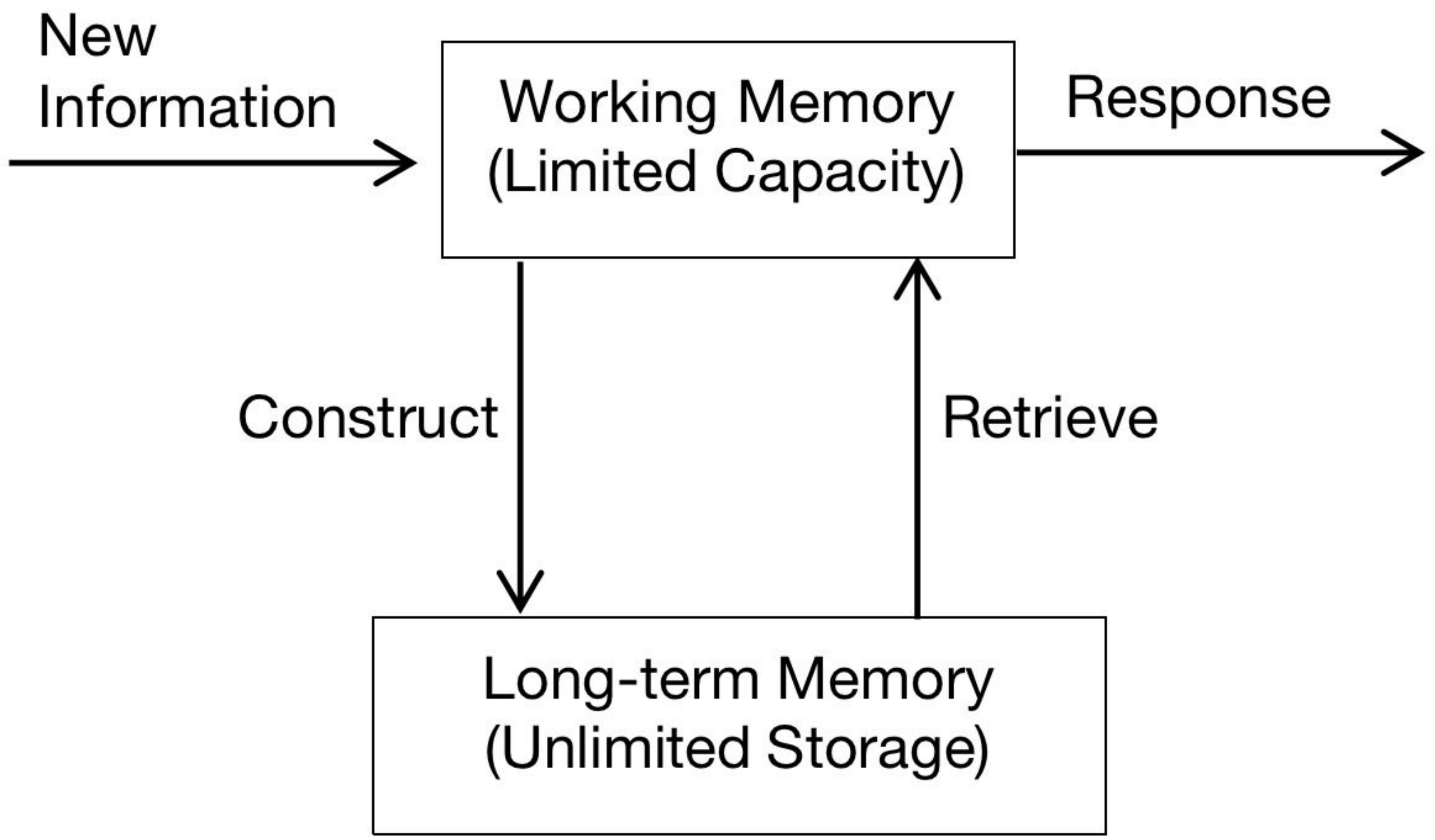
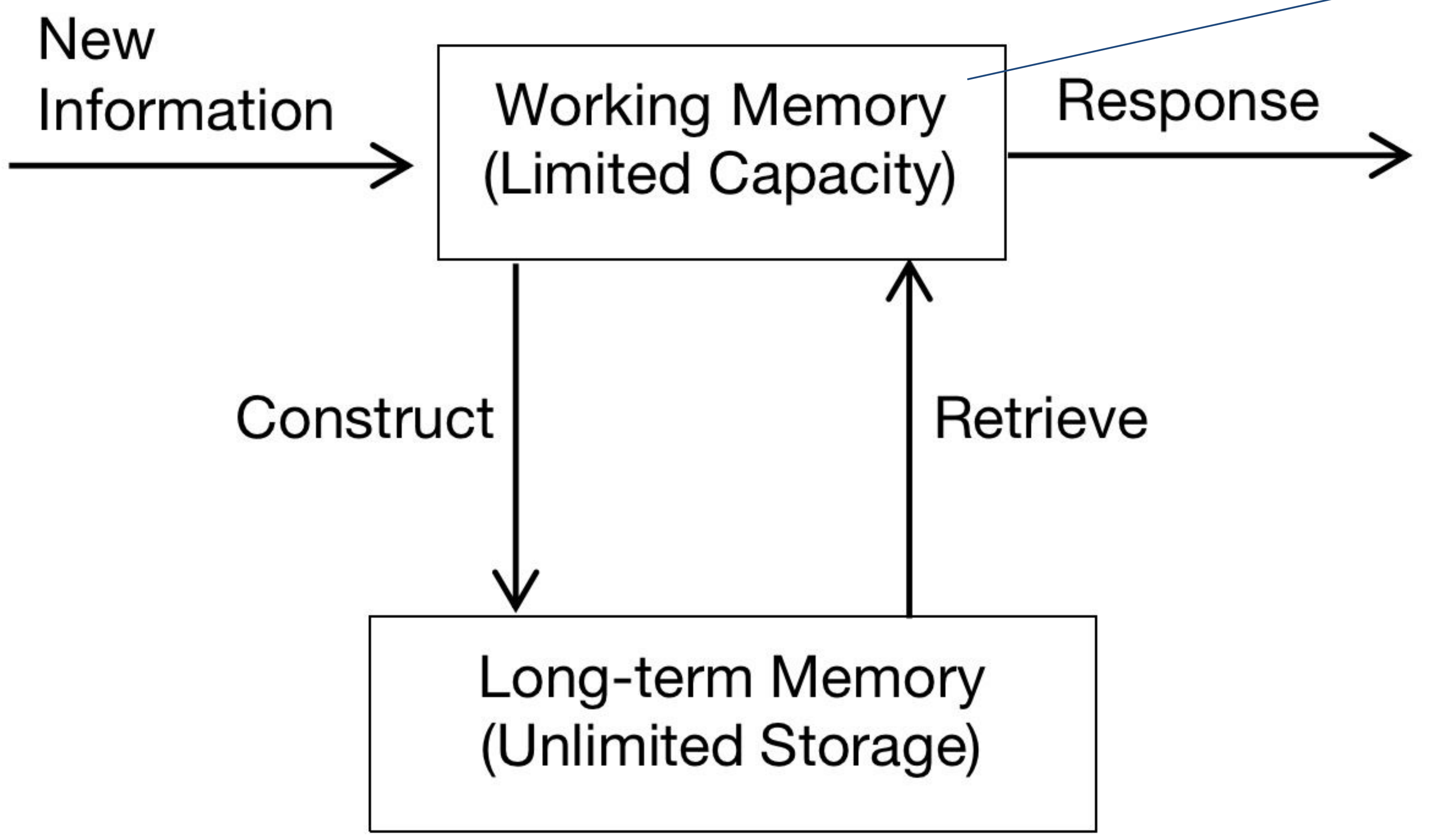
# Cognitive Load Theory (CLT) [3]

*Why MATLAB works/ does not work?*



# Cognitive Load Theory (CLT) [3]

*Why MATLAB works/ does not work?*




**Intrinsic load** refers to the complexity of the information being processed and the knowledge to process that information.

**Extraneous load** is related to how information is delivered to learners. It could be reduced by effective instructional approaches that lower the complexity of interactions between elements. (Sweller, 2020)

# Methods

Participants: School A (3), School B (6)

**Table 1. Characteristics of the Schools**

| School Name | Type of School | Student-Teacher Ratio | Total Students | Title I Eligible | Female Students % | Minority Enrollment % | Black (%) | Asian (%) | Hispanic (%) | White (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| School A | Public | 14 | 279 | YES | 49 | 96 | 77 | 0 | 17 | 4 |
| School B | Public | 20 | 1756 | NO | 51 | 20 | 2 | 10 | 3 | 80 |

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# Methods

## Interview & Coding

Semi-structured student focus groups:

1. Usage of MATLAB in Designing Water Filter
2. Positive Aspects of MATLAB
3. Challenges with MATLAB
4. Suggestions for Improvement
5. Understanding of Model Definitions
6. Curiosity about Underlying Code
7. Desire for Additional MATLAB Tools
8. Previous Experience with Programming

1 Students' perspective

Previous Codebook [4]

2 CLT Load

Intrinsic & Extraneous

3 Instructional Effects

# Main Findings

## *RQ1: What in MATLAB helps & Why*

- measure various materials accurately and provide precise data, saving them time on extensive material testing.
- promoted engagement by the feeling of real-world modeling.
- helped in their prototype design.

CLT: MATLAB tool reduced the **intrinsic load** in their learning.

*"I think it was just really helpful in regards to how rigorous [it is]. [I] actually felt it was filtrating water and [I see] how efficient it was and how much water would be filtered in percentage rates."*

```
% consider all media diameters (m)
dcAll = (0.4:0.001:2)/1000; %all the points of interests define the size of the matrix
[LRV,R] = setUpParameters(dc,e,L,g,dp) ;
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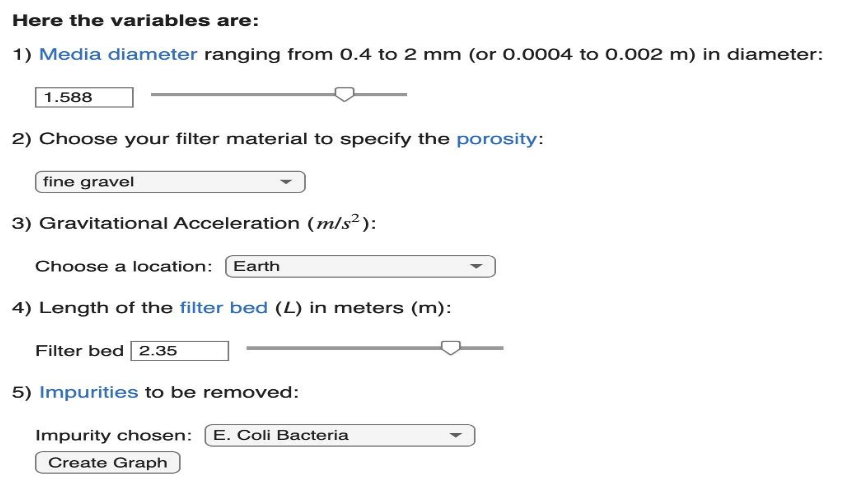


# Main Findings [5]

## *RQ1: What in MATLAB helps & Why*

4) the graphing function of the platform

CLT: The presentation of images reduced the **split-attention effect in extraneous load**.

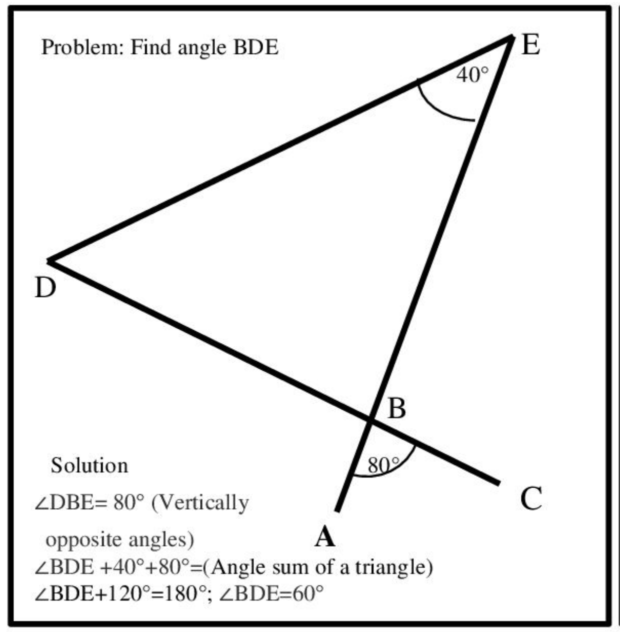



*Figure 1. 1*: Split attention format.
*Source: Ayres & Sweller (2005:208).*

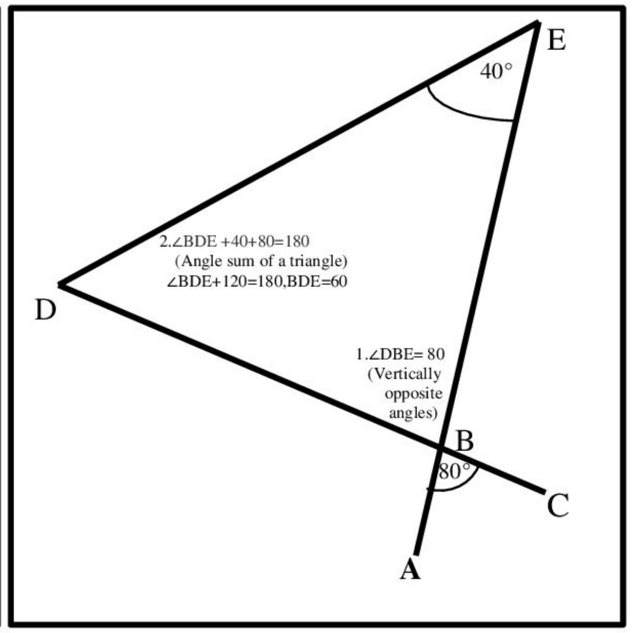
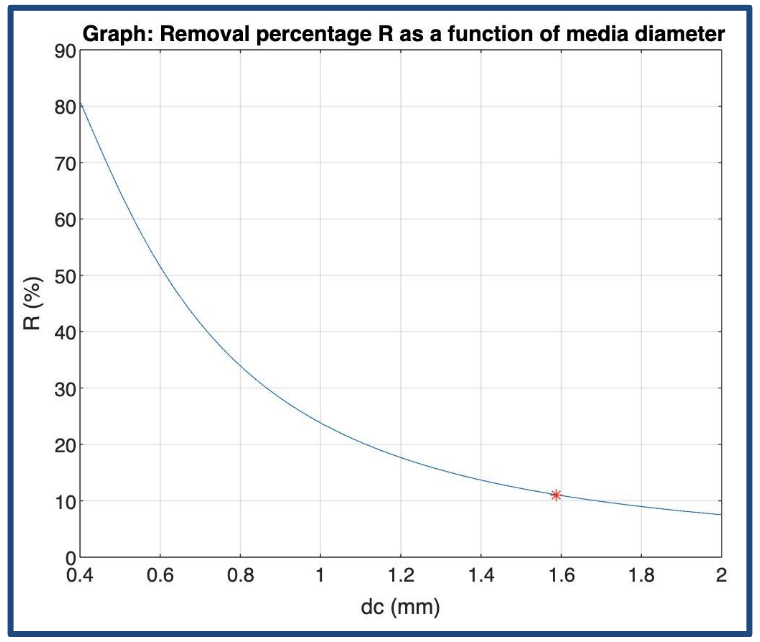



*Figure 1. 2*: Integrated format.
*Ayres & Sweller (2005:209).*




*"I also liked how the program gave us a nice little graph that showed us whether it filtered badly, so we wouldn't have to keep on adjusting..."*

# Main Findings

## *RQ2: What to improve & Why*

1) the challenges of measuring real-world materials and aligning the physical prototype with the simulation.

CLT: The students' frustration pointed to the **variability effect within the extraneous load**. It proposes substituting tasks that are similar with tasks that differ to enhance the transfer of learning.

*"It's really hard to figure out the media diameters of the different ones…depending upon which one you use. If you use just random gravel you find on the road or specifically manufactured gravels for maybe aquariums or something like that. That was definitely difficult, especially with those smaller ones where it was really hard to measure."*

# Main Findings

## *RQ2: What to improve & Why*

2) demand for more detailed explanations of the code and mathematics behind the MATLAB models to facilitate better understanding.

CLT: For students, the intrinsic and extraneous loads were different during the learning process.

*"... if there was a way to better explain, like what each part does, and more detail, to help show the math behind it, because at the end of the day, it's coding, but it's also a lot of math involved with creating those different models.*

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# Main Findings

As a result, we found the benefits of mathematical modeling with MATLAB in **informing** their engineering design decisions by allowing the **testing** of different materials and providing precise **simulating** results. However, challenges arose regarding the **gap between simulation and prototype** building. From the perspective of CLT, MATLAB helped **reduce** intrinsic load by minimizing prior knowledge requirements. Yet it was still crucial for managing multi-layered intrinsic loads and effectively **dealing with extraneous loads**.

# Limitations

- The sample size was limited to students from only two schools.
- Reliance on self-reported data from students.

# References

[1]Engineering for us all democratizes and demystifies engineering for all. e4usa. (n.d.). https://e4usa.org/node/148
[2]Teachengineering.TeachEngineering.(n.d.).https://www.teachengineering.org/e4usa
[3] **J. Sweller, J. J. G. Van Merriënboer, and F. Paas, "Cognitive Architecture and Instructional Design: 20 Years Later," Educ. Psychol. Rev., vol. 31, no. 2, pp. 261–292, Jun. 2019, doi: 10.1007/s10648-019-09465-5.**
[4] N. Léger, S. S. Klein-Gardner, and B. T. Berhane, "Board 178: Teacher Perspectives of Outcomes and Challenges Resulting from Students' Interactions with MATLAB in e4usa (Fundamental)".
[5] Sithole, S.T. (2015). Self-management of cognitive load in accounting within a Zimbabwean University context.

# Thank you!

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