

Board 178: Teacher Perspectives of Outcomes and Challenges Resulting from Students' Interactions with MATLAB in e4usa (Fundamental)

Mr. Nicolas Léger, Florida International University

Nicolas Léger is currently an engineering and computing education Ph.D. student in the School of Universal Computing, Construction, and Engineering Education (SUCCEED) at Florida International University. He earned a B.S. in Chemical and Biomolecular Engineering from the University of Maryland at College Park in May 2021 and began his Ph.D. studies the following fall semester. His research interests center on numerical and computational methods in STEM education and in Engineering Entrepreneurship.

Dr. Stacy S Klein-Gardner, Vanderbilt University

Dr. Stacy Klein-Gardner serves as an Adjunct Professor of Biomedical Engineering at Vanderbilt University. She is the co-PI and co-Director of the NSF-funded Engineering For Us All (e4usa) project. She is also the co-PI and co-Director of the Youth Engineering Solutions (YES) Middle School project focusing on engineering and computational thinking. Dr. Klein-Gardner is a Fellow of ASEE.

Dr. Bruk T Berhane, Florida International University

Dr. Bruk T. Berhane received his bachelor's degree in electrical engineering from the University of Maryland in 2003. He holds an M.S. in engineering management from the George Washington University and a Ph.D. in minority and urban education from the University of Maryland. In 2003, Bruk was hired by the Johns Hopkins University Applied Physics Laboratory (JHUAPL), where he worked on nanotechnology and microsystems. In 2005 he left JHUAPL for a fellowship with the National Academies and researched methods of increasing the number of women in engineering. Later that year, he briefly served as a mathematics instructor in Baltimore City High Schools.

From 2005 through 2018, Dr. Berhane directed engineering recruitment and scholarship programs for the University of Maryland. He oversaw an increase in the admission of students of color and women during his tenure and supported initiatives that reduce the time to degree for transfers from Maryland community colleges. The broader implications of his research are informed by his comprehensive experiences as a college administrator. His areas of scholarly interest include: 1) Broadening participation in engineering through community college pathways and 2) Experiences of first and second-generation African diasporic Americans in engineering undergraduate programs.

Teacher Perspectives of Outcomes and Challenges Resulting from Students' Interactions with MATLAB in e4usa (Fundamental)

Abstract

As part of the e4usa curriculum, a MATLAB model has been developed and implemented in order to cultivate engineering and computational thinking skills in high school students. The MATLAB model uses a live script that allows students to interact with sliders and dropdown menus to change parameters on a water filtration model. With computational skills increasingly in demand, the literature suggests that adding computational thinking and coding skills as a new form of literacy is crucial for preparing future engineering professionals. Additionally, to ensure that students are better prepared by the time they reach their post-secondary studies, early exposure to computational thinking skills has valuable implications.

In this fundamental paper, we describe outcomes resulting from students' interactions with MATLAB in e4usa. The mathematical model allows the students to analyze the effects of different filtration materials, impurities to be removed, length of the water filter, and the space between particles in their filtration material. Using at first a mathematical model rather than testing physical materials will allow them to learn more about their potential filtration materials so that they may make more informed decisions about which filtration materials they want to select for their design and use in the prototype that they build and test. With that said, we focus on student outcomes in this design activity. We hypothesize that this modeling activity prior to design may reduce the time spent in physical testing as well as the volume of materials consumed. Additionally, we are inquisitive about the impact that it has on the subsequent design activities compared to previous semesters where this lesson was taught, where it was observed that students spend a considerable amount of time trying out different materials.

As part of our data, we have collected teacher data from surveys, pre and post-responses about their expectations, attitudes, and perceived value of implementing the MATLAB model in their classrooms, class observation data from at least two schools where we noted the interactions between the teachers and students, and teacher and student focus groups at the end of the semester where we expect to collect richer data from these two groups that will allow us to triangulate data collected from surveys and classroom observations.

Introduction

The goal of the NSF-funded effort, e4usa, is to advance knowledge and understanding of how high school-level engineering curriculum and related professional learning might be developed to foster the diversity and the number of high school educators and students engaged in engineering. The curriculum presents this new approach to engineering through four major concepts: connecting with engineering, engineering in society, engineering professional skills, and engineering design. e4usa attempts to pique the attention of both students and instructors. In that regard, as part of our curriculum, a mathematical modeling tool, based on the MATLAB live script environment, has been implemented in order to broaden the experience of our students with engineering design. MATLAB was chosen due to its blend of text, comments, images,

equations, and programming that makes engineering modeling and programming more attractive to the students that are new to it [1],[2]. One of the most important skills that engineers have is their ability to do engineering modeling informed by STEM principles. In addition to fostering engineering design thinking, this newly added lesson aims to develop students' computational thinking skills, which are increasingly important in our current economy. This lesson aims to benefit students in their future career endeavors either in engineering or other fields. Furthermore, to ensure that students are better prepared by the time they reach their post-secondary studies, early exposure to computational thinking skills has valuable implications [2],[3].

Project Overview and Introduction to the Tool

A lesson entitled, *Researching a Water Filter: Mathematical Modeling*, has been introduced into the e4usa curriculum. This lesson is based on the newly designed MATLAB model, using a live script where the students can change parameters on the water filtration model implemented in the *Design Selection* section as part of Unit 2 (see Appendix A). Through this unit, students are able to participate in a guided engineering challenge that involves developing a solution to a global issue. In Unit 1 and 2, they are provided with the necessary skills and knowledge to design and construct a prototype that can address a specific need. The project is based on the NAE's Grand Challenges, which states that the world's water supply is facing increasing threats [4]. After forming teams and learning about effective teamwork, teams progress through the steps of the engineering design process. This involves identifying constraints and success criteria, reviewing relevant scientific information, coming up with design solutions using the MATLAB tool, building prototypes, and creating a plan for testing. Finally, teams must consider how to improve their design and effectively communicate their solution to relevant parties.

In this activity, the students are prompted by their teacher to create a water filter on their camping trip to substitute for the filter they left at home using only materials found in their backpack. Their goal is to remove impurities in the water that their teacher gives them and make the water more potable. The mathematical model here allows them to analyze the effects of different filtration materials, impurities to be removed, length of the water filter, and the space between particles in their filtration material based on the Crittenden et al.'s [5] book example. The tool allows the students to test only one material at a time; they then can save their trials by saving the graph displaying the performance curve and the text output at the bottom of the modeling sheet displaying the model inputs and corresponding outputs (*See Appendix A Fig 2.*).

Using at first a mathematical model rather than testing physical materials allows the students to learn more about potential filtration materials. This allows students to make more informed decisions about which filtration materials they want to select for their design and use in the prototype that they build and test. In addition, mathematical modeling can be very demanding to perform by hand because of the quantity of calculations or the advanced level of mathematics. Therefore the MATLAB programming platform was chosen to ease that task. Using the MATLAB .mlx interface in "Hide code" mode does not require students to code in order to use the model, and is more geared towards practicing engineering design and computational skills [6].

Aim of project

In this paper, we aim to describe outcomes and challenges resulting from students' interactions with MATLAB in e4usa. The specific research questions addressed are:

RQ 1 How did the MATLAB tool help students in their subsequent design activity? To what extent did students enjoy using a mathematical model to inform their engineering design decisions?

RQ 2 What were the challenges faced by the students using this tool and suggested areas of improvement for it?

RQ 3 Were the students curious about the actual code behind this tool, in other words, did the student go beyond the mathematical modeling interface to the coding window?

Background

In K–12 education, computational thinking is becoming increasingly important, especially in relation to engineering decision-making, as evidenced by the rising corpus of research on the subject. A core ability that can aid students in developing their problem-solving abilities, logical reasoning, and creativity is computational thinking [3], [7]. Moreover, Wing suggests that computational thinking “complements and combines mathematical and engineering thinking...as computer science inherently draws on engineering thinking, given that we build systems that interact with the real world” [7]. To date, there has been a growing focus to include computational thinking in K–12 curriculum, especially through the teaching of computer science and coding skills [8]–[12].

However, there is a gap in the literature regarding how to effectively integrate computational thinking and engineering design into K-12 education. While there are some programs and initiatives that have incorporated these concepts, there is still a lack of consensus on best practices and how to measure student outcomes. For this reason, understanding ways in which students engage with this newly implemented lesson in the curriculum was of primary importance.

Positionality Statement

In this paper, the primary author draws from his experiences using computational tools as an undergraduate student in Chemical and Biomolecular Engineering. As an undergraduate student, he along with several fellow students struggled with a lack of understanding in a required course in numerical and computational methods (NCM). Despite the fact that he obtained a good grade in this course, he did not retain or fully grasp much of the information taught in this course. He eventually learned these skills while working at research laboratories and by doing some personal research on mathematical modeling. As a result, this motivated him to explore the topic of numerical and computational methods in engineering and computing education, which can

subsequently help to broaden the understanding of these methods and ensure that future students have a better experience learning and applying these tools in their work. He is currently a doctoral student in engineering education and developed the MATLAB based tool described in this paper with the support of MathWorks®.

Study Context

This study is a component of a larger NSF-funded project, e4usa, which began in 2018. e4usa's intent is on advancing knowledge and understanding of how high school-level engineering curricula and related professional learning can be designed to increase the number and diversity of high school teachers and students participating in engineering, while keeping at core inclusivity for all students and teachers [18]. Furthermore, the curriculum's goal is to highlight the concept of thinking like an engineer rather than just developing more engineers.

Methods

For this paper, we share a full analysis from a teacher focus group with four teachers. In this focus group, we asked these instructors about their classroom experiences with the MATLAB tool. These teachers taught the lesson between one and two class periods. We report specifically on experiences that the teachers reported in the focus groups as it related to their students' overall engagement with MATLAB. Table 1 below presents the teachers' school background and demographic information.

Participants

Table 1

Participant background and demographic information.

Teachers	State	Type of School	% of Students Receiving Free Lunch	Teacher Status	Course Section	Total number of Students in Course Section	Freshmen	Sophomores	Juniors	Seniors	Female	Male	Hispanic/Latinx	Asian	Black/African American	White	Two or More Races	Race Not Listed
Paul	PA	Public	95.9	3rd and 4th Year Returning Teacher	Elective	20	0	0	8	12	10	10	2	1	2	16	0	1
Karla	FL	Public	95.9	New Teacher	Within another course	23	0	2	8	13	10	13	5	0	12	3	1	7
Sandra	TN	Public	Unavailable	New Teacher	Elective	6	0	0	0	6	1	5	4	0	2	0	0	4
Franck	VA	Private	Unavailable	New Teacher	Elective	17	17	0	0	0	17	0	0	1	0	16	0	0

Data Collection and Analysis

We conducted teacher end-of-semester semi-structured focus groups after implementing the new MATLAB activity. The focus group questions were centered around seven main topics:

- Did the teachers chose to use the tool in their classroom
- How long did it take to prepare for it
- Did they have prior knowledge using MATLAB or a similar modeling software
- How useful was this tool in their classroom, their thoughts about the tool (good and area of improvement)
- The students' reactions to the MATLAB tool
- The benefits that their students found in using this tool
- The impact that the tool had on the final design of Unit 2 (compared to other years for returning teachers) and the overall enjoyment of using mathematical modeling to inform their engineering design decisions.

The focus group was conducted online over Zoom and was recorded. The audio file was uploaded to Microsoft Word Online to be transcribed, where the transcript was corrected by hand as needed. The transcript was uploaded into Dedoose v9.0, which is a cloud based qualitative and mixed method data analysis tool [19]. The next step was to code the transcript inductively; the co-authors first individually coded the transcript. After the individual coding was complete, the team discussed the individual code books and agreed on a final master code book (*See Appendix B*).

Results

In this paper, when referencing students, we talk about what teachers shared about their students' experiences. We acknowledge that we do not share findings associated with the students' perspectives themselves, but rather focus on the students' experiences from the teachers' perspectives. Future work will include student focus group data. Additionally, we define "new teachers" as instructors who are teaching the curriculum for the first time and "returning teachers" as instructors teaching the curriculum for at least the second time. For this study, we had three new teachers and one returning teacher. We refer to these teachers in this paper using pseudonyms selected by the research team.

We describe the findings drawn from the focus groups below, and we organize our findings around the three research questions presented earlier. Emergent themes describing teachers' reports on their students' interaction with the tool are described below. We define the first theme, described in responding to Research Question 1, as *Benefits of and engagement with the tool*. The second theme, explained in answering Research Question 2, is *Lack of engagement with the tool*. The third theme is *Curiosity about the tool*, which is articulated in our answer to Research Question 3.

The themes all map onto parent and/or child codes presented in Appendix B. For example, the findings provided under *Benefits of and engagement with the tool* are drawn from the parent code *Recognition of relevance of MATLAB – Students demonstrate an appreciation for how MATLAB can be useful* as well as its associated child codes. Findings provided under *Lack*

of engagement with the tool are derived from the following two parent codes and their associated child codes: *Parent code: Relevant prior experience - Students have done some prior work that makes their experience with MATLAB more impactful, meaningful, efficient, etc.* and *Challenges using MATLAB – Students have some difficulty using MATLAB.*

RQ 1: Benefits of and engagement with the tool

The first research question aims to capture how the MATLAB tool benefited students in their subsequent design activity. The emergent themes depict the students' recognition and relevance of MATLAB in their work and the extent to which they appreciated the tool. Teachers reported that when working on building their water filters, students used information derived from the MATLAB model in coming up with solutions, designs, etc. Karla, one of the new teachers, reported the following:

I had a student who was using the cheesecloth and she was like, you know what? No, I don't think I want to use this anymore because I just don't think she's like where I placed it. It's probably not the right place to put it...I want to change that out. So she went back and changed her design. And so I think it has its advantages.

Karla continued, saying:

I think for some of them, well, they're in groups, so what I did is as a group, I told everyone in the group would sketch their own design of how they think it should look like based on their prior research, and then I told them to pick the three that they thought were really good...prototypes that they can use and kind of compare amongst them and then...at the end they would be able to go back and say... which prototype would best and then which one they would improve on so I had them sketch that and then use them... and then from that they were kind of able to decide if they were going to change parts of their design, but not a lot of them changed everything, but it did get them thinking about when they actually build.

A new teacher, Franck, reported that:

I think probably the impact of the design...seemed like a couple of the groups actually try to decide which materials to use based on which ones seem to more the type of material that they could see. There was a relationship getting into details, but just at least which type of materials they tried to select, at least for their first pass,...and...there was one or two kids who did kind of get into it,...a little more like playing with it beyond the tables...and this only does this much and you know they were curious and playing like a game so that was good to see.

Similarly, another new teacher, Sandra, reported that:

They really did like being able to do it versus plugging in some of their own stuff they didn't have to keep reading, running, keep redoing, they could just...buy all the materials. Granted I bought them a couple years ago, didn't get to use them for COVID but limited amount of materials so we didn't have to worry about running out. They knew it was

going to work, and basically they turned it into a game where they could find out who could filter out the most cooties..., because they were trying. None of them did very well with E. Coli, but they were doing really well on the others.

Similarly, the returning teacher, Paul, reported that:

I think my kids love the idea of the whole thing like they recognize how it would be useful pretty much right away that they wouldn't have to do kind of a trial and error approach, but then I think they got a little bit frustrated with when they got down to the details of it and realized, wait a minute, we can't have a meter and a half filter bed in this little thing and then when they brought those numbers down, they realized the percentages would be on the lower side and they felt like that was ineffective and I think their perfectionism was frustrated by the fact that they weren't going to be able to remove all of any kind of nasties that would be in the water...I had a couple of my kids that were in a microbiology class so they bolted down with our samples to "micro[biology classroom]" and to find out that everything had everything in it. It was growing like crazy, which was kind of scary and so they were sort of hard on themselves in terms of their design that work the way they wanted to do, virus vs bacteria kind of situation that we're filtering out of the dirty water.

These excerpts demonstrate that to some extent, the students are thinking about their iterations using the modeling tool and thinking about what the results really mean in real world applications in their design. We also found that some students interacted with the MATLAB live scripts interface as a “game” and showed some level of excitement using it. When Sandra mentioned that “None of them did very well with E. Coli”, she is referring to the performance curve on the model that allows the students to know which parameters of the model perform better (*See Appendix A Fig 2.*); in this case, based on their chosen parameters, the students had very low percent removal. Moreover, some students also found some connections between their engineering class and their microbiology class.

RQ 2: Lack of engagement with the tool

The second research question aims to capture the challenges faced by the students using this tool and suggested areas of improvement for it. The emergent themes depict the students’ lack of recognition of the relevance of the tool, where students do not demonstrate an appreciation for it. We offer these findings not as a critique of the students, but to share ways in which there appeared to be a disconnect between the tool’s utility and students’ engagement. Teachers reported that some students missed the “so what” or bigger picture or doing work in MATLAB but not seeing how it can help solve challenges in the broader context. For example, Karla reported that:

They're just like, oh, the numbers are changing...The percent removal you know the contaminant based on the different changes, they have to come to a final conclusion of...is this a good filter or is this not a good filter? Did it increase the amount of contaminants being removed or did it decrease? Like what is it? You know from the math part they could kind of see that not all of them. Some of them I had to kind of guide them to that answer,because they just weren't sure. They're like, “Well, what am I comparing,..what am I supposed to be looking for?” So I think it could have been a video.

A video could work, but it could also be maybe a model...They could see the changes in the graph,...but I don't know if it...made sense, I don't know if they connected really with them...like we're doing this and the computer's doing this for us and kind of saving the time. Yeah that part I don't know which is 100%...I thought maybe it would have been good for them to actually see like a sort of like a a second piece to where they you know if there was like a simulation where it's like the water is being poured and then it shows them what it would look like, the color of the water if there would be a color change or not color change, or if they could actually see the contaminants being kept or or filtered out. I don't know if that's possible and I'm not sure if that's part of the piece that you guys are looking for.

Similarly, Franck stated that:

You know some of the kids were not as technically inclined. I don't think [they] really got what was going on, they were just plugging in numbers and writing stuff down so,...,they didn't really because it [the activity]...was like one class period and then the next class period, you know they would actually...build their filter and stuff, and I don't know if many of them really made a real clean connection that the one is supposed to impact how they design their filter. Some did, but some really didn't, I guess because one is in the computer and one is physical, they just didn't really make that connection. A lot of them, some did, but a fair number didn't.

These excerpts demonstrate that some students missed the reason for using a simulation tool and the benefit that it has. It is not evident to some students how the work that they are doing in MATLAB translates to work in their physical engineering project. Additionally, the teachers make some recommendations on how to improve the visuals of this lesson that would allow the students and teachers to have a better appreciation of the filtration process.

RQ 3: Curiosity about the tool

The third research question aims to capture the students' curiosity about the code behind the tool, if they went beyond the mathematical modeling interface to the coding window in MATLAB. The emergent themes depict that there are mixed responses from different teachers. Franck mentioned that:

You know there was one or two kids who did kind of get into it...who were a little more like...playing with it beyond the tables that I gave [to] them. They're like wow...this does this and...this only does this much and you know they were...curious and playing like a game.

whereas Karla stated that “from when I was walking around the room I don't think any of them did that. I think they were just more or less just trying to make sure they got the parameters right.” Overall, most students focused on the primary engineering design objective with some rare occasion digging into the coding view of the tool.

Discussion, Implications, and Future Work

Understanding ways in which students engage with this new lesson in the curriculum has the possibility to shape the future of pre-university engineering programs. By exposing students to engineering design and computational skills, they will be better prepared to pursue baccalaureate and even advanced engineering degrees. As noted by Barr et al:

It is no longer sufficient to wait until students are in college to introduce these concepts. All of today's students will go on to live a life heavily influenced by computing, and many will work in fields that involve or are influenced by computing. They must begin to work with algorithmic problem solving and computational methods and tools in K-12.[3]

The findings here provide us with some insight into the student outcomes in this design activity informed by mathematical modeling powered by the MATLAB live script interface. Emergent themes demonstrate that some students are thinking and engaging deeply with the modeling tool. Results also show that they are using the tool to consider real world applications in their design. This reflects findings from Botelho et al., who suggest that the educational use of a computer simulation is the emphasis on exploring by running the simulation numerous times. This allows students to examine various scenarios and assumptions as part of the “theory-building process”[13]. This then allows the students to gain some hands-on experience at the comfort of their computer, with the flexibility of running the model as many times as needed. It also allows them to take note of their iterations as part of their scientific inquiry (*See Appendix A Fig 2.*).

Additionally, an interesting finding was that teachers reported that some students interacted with the MATLAB live scripts interface as a “game” and showed some level of excitement using it. This is particularly interesting as this tool might have a familiar interface that piques the interest of the students more readily than traditional pen and paper class activities. Similarly, Deshpande et al.[14] noted that engineering topics can be presented in new and innovative ways through the use of computer simulation games, interactive environments, and refined graphics. These can be utilized to stimulate students' problem-solving and presentation skills. Moreover, through the use of simulation tools, students can learn how to make their own decisions and manage their mistakes in a real-world setting [14]. In parallel to simulation tools, other technology-based learning experiences in engineering education such as virtual reality have been reported to increase students' “cognitive and pedagogical gains” leading to an increase in performance and grades [15].

Other emergent themes include the students' lack of engagement with the tool or lack of appreciation for and other challenges associated with the tool. The underlying purpose and benefits associated with using the tool may not have been readily apparent to the students. As noted in the findings, it was not evident to some students how the work that they were doing in MATLAB translates to work in their physical engineering project. It is to be noted that this is the first time that this activity was implemented in the classroom, and that the activity lasted for a short duration of time. In fact, it would likely have required more time for some students to adapt to it and to become more adept using it. In that regard, educational psychologists Mayer et al. recommend “pre-training” where the students are acquainted with the multimedia system where they will be completing a task before completing the desired activity, allowing them to construct mental models and build confidence [16]. Lyon et al. in the context of using MATLAB in a

capstone engineering class reported that “pre-training is often able to lessen the amount of information that a student needs to process at any given time during a learning task” [17]. Moreover, a teacher mentioned that the activity was only covered during one class period and could have been rushed for some. Furthermore, in addition to the teacher’s manual and student’s handout, teachers made some recommendations on how to improve the visuals of this lesson, where instead of the introductory image (*See Appendix A Fig 1.*), a video showing a dynamic simulation of the water filter would be appreciated by the students and teachers. This would allow for an opportunity of “pre-training” by providing better visuals and explanations of the task.

Areas for future research

This current work only looked at what teachers shared about their students’ experiences. Further expansion of this work will involve looking at our class observations, student focus groups, and teacher surveys which will include quantitative statistical analysis. This work will allow us to further our understanding of computing tools that may help with engineering design at the K-12 level. In addition, suggestions collected from the tool will be implemented and could also lead to future studies.

Acknowledgements

This material is based upon work supported by the National Science Foundation under Grant No. EEC-2120746. We also would like to acknowledge the support of MathWorks® in our effort to develop this tool.

References

- [1] N. Nevaranta, P. Jaatinen, K. Gräsbeck, and O. Pyrhönen, “Interactive Learning Material for Control Engineering Education Using Matlab Live Scripts,” in *2019 IEEE 17th International Conference on Industrial Informatics (INDIN)*, Jul. 2019, pp. 1150–1154. doi: 10.1109/INDIN41052.2019.8972282.
- [2] N. Leger and B. Berhane, “Work in Progress: A Literature Review On Computational & Numerical Methods in Engineering Education,” presented at the 2022 ASEE Annual Conference & Exposition, Aug. 2022. Accessed: Sep. 05, 2022. [Online]. Available: <https://strategy.asee.org/work-in-progress-a-literature-review-on-computational-numerical-methods-in-engineering-education>
- [3] V. Barr and C. Stephenson, “Bringing computational thinking to K-12: what is Involved and what is the role of the computer science education community?,” *ACM Inroads*, vol. 2, no. 1, pp. 48–54, Feb. 2011, doi: 10.1145/1929887.1929905.
- [4] “Grand Challenges - Provide Access to Clean Water.” <http://www.engineeringchallenges.org/challenges/water.aspx> (accessed Jan. 31, 2023).
- [5] J. C. Crittenden, K. J. Howe, D. W. Hand, G. Tchobanoglous, and R. R. Trussell, Eds., *Principles of water treatment*, Third edition, Student edition. Hoboken, New Jersey: John Wiley & Sons, Inc, 2012.
- [6] “Add Interactive Controls to a Live Script - MATLAB & Simulink.” https://www.mathworks.com/help/matlab/matlab_prog/add-interactive-controls-to-a-live-script.html (accessed Jan. 31, 2023).
- [7] J. M. Wing, “Computational thinking,” *Commun. ACM*, vol. 49, no. 3, pp. 33–35, Mar. 2006, doi: 10.1145/1118178.1118215.
- [8] “Framework Statements by Concept,” *k12cs.org*. <https://k12cs.org/framework-statements-by-concept/> (accessed Apr. 14, 2023).
- [9] “Code.org 2021 Annual Report,” *Code.org*. <https://code.org/about/2021> (accessed Apr. 14, 2023).
- [10] “Black Girls Code — Women of Color in Technology,” *Black Girls Code — Women of Color in Technology*. <https://www.blackgirlscode.com> (accessed Feb. 09, 2022).
- [11] A. Montoya, “Computer Science for All: Opportunities Through a Diverse Teaching Workforce,” *Harv. J. Hisp. Policy*, vol. 29, pp. 47–62, 2017.
- [12] J. Maloney, M. Resnick, N. Rusk, B. Silverman, and E. Eastmond, “The Scratch Programming Language and Environment,” *ACM Trans. Comput. Educ.*, vol. 10, no. 4, pp. 1–15, Nov. 2010, doi: 10.1145/1868358.1868363.
- [13] W. T. Botelho, M. das G. B. Marietto, J. C. da M. Ferreira, and E. P. Pimentel, “Kolb’s experiential learning theory and Belhot’s learning cycle guiding the use of computer simulation in engineering education: A pedagogical proposal to shift toward an experiential pedagogy,” *Comput. Appl. Eng. Educ.*, vol. 24, no. 1, pp. 79–88, 2016, doi: 10.1002/cae.21674.
- [14] A. A. Deshpande and S. H. Huang, “Simulation games in engineering education: A state-of-the-art review,” *Comput. Appl. Eng. Educ.*, vol. 19, no. 3, pp. 399–410, 2011, doi: 10.1002/cae.20323.
- [15] M. Soliman, A. Pesyridis, D. Dalaymani-Zad, M. Gronfula, and M. Kourmpetis, “The Application of Virtual Reality in Engineering Education,” *Appl. Sci.*, vol. 11, no. 6, p. 2879, Mar. 2021, doi: 10.3390/app11062879.
- [16] R. E. Mayer and R. Moreno, “Nine Ways to Reduce Cognitive Load in Multimedia Learning,” *Educ. Psychol.*, vol. 38, no. 1, pp. 43–52, Jan. 2003, doi: 10.1207/S15326985EP3801_6.
- [17] J. Lyon, A. Jaiswal, and A. Magana, “The Use of MATLAB Live as a Technology-enabled Learning Environment for Computational Modeling Activities within a Capstone Engineering Course,” in *2020 ASEE Virtual Annual Conference Content Access Proceedings*, Virtual On line: ASEE Conferences, Jun. 2020, p. 35380. doi: 10.18260/1-2--35380.
- [18] R. Figard, M. Dalal, J. Roarty, S. Nieto, and A. Carberry, “Understanding High School Student Experiences in an Engineering Course Designed For All (Fundamental, Diversity),” presented at the

2022 ASEE Annual Conference & Exposition, Aug. 2022. Accessed: Jan. 18, 2023. [Online]. Available:

<https://peer.asee.org/understanding-high-school-student-experiences-in-an-engineering-course-designed-for-all-fundamental-diversity>

[19]“Home | Dedoose.” <https://www.dedoose.com/> (accessed Jan. 26, 2023).

Appendix

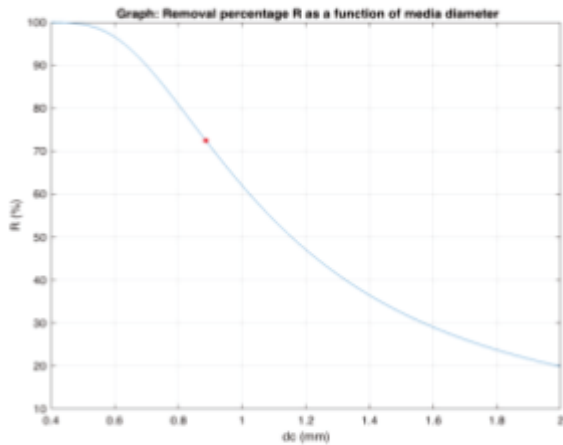
Appendix A

As a note, the MATLAB tool described in this paper can be accessed by clicking [here](#). By clicking on “Launch this activity”, you will access the mathematical model as shown below.



Fig 1. Main view of the MATLAB modeling page where the model parameters are adjusted using these drop down menus and sliders

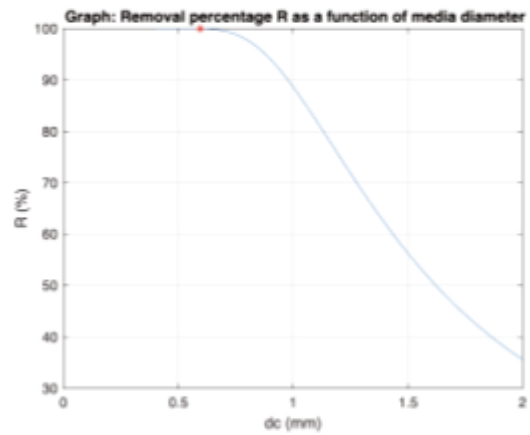
Trial #1



In summary, using fine gravel as the filtration material, the filtration media porosity is 0.52. We are using a media diameter of 0.8852 millimeters, a water filter length of 1.53 m, and an impurity of diameter 8.8 um. On earth, gravity is 9.81 m/s².

Your filter removes 72.49% of the Giardia Lamblia.

Trial #2



In summary, using sand as the filtration material, the filtration media porosity is 0.41. We are using a media diameter of 0.5968 millimeters, a water filter length of 1.77 m, and an impurity of diameter 8.8 um. On earth, gravity is 9.81 m/s².

Your filter removes 99.97% of the Giardia Lamblia.

Fig 2. Graph displaying the performance curve of the chosen parameters displaying the removal percentage (R) and text output at the bottom of the modeling sheet displaying the model inputs and corresponding outputs

Appendix B

Parent code: Recognition of relevance of MATLAB – Students demonstrate an appreciation for how MATLAB can be useful

Child code: Students make design decisions based on results – When working on an engineering project, students use information derived from MATLAB in coming up with solutions, designs, etc.

Child code: Students see the value of the MATLAB tool – Students show that they understand at least some of the benefits of MATLAB

Child code: Students seek to validate tool – Participants in the course attempt to confirm or verify what MATLAB is telling them with respect to a project, task, etc.

Parent code: Lack of recognition of the relevance of MATLAB – Students do not demonstrate an appreciation for how MATLAB can be useful

Child code: No connection between computational and physical models – It is not evident to students how the work that students are doing in MATLAB translates to work in their physical engineering project, task, etc.

Child code: Missing the “so what” or bigger picture – Students may be doing work in MATLAB but not seeing how it can help solve challenges in the broader context

Parent code: Relevant prior experience - Students have done some prior work that makes their experience with MATLAB more impactful, meaningful, efficient, etc.

Child code: Prior coding experience - Students have done some prior programming that makes their experience with MATLAB more impactful, meaningful, efficient, etc.

Child code: Familiarity with MATLAB – There is a reference to prior experience with MATLAB

Child code: Reduced learning curve due to prior experiences with software – There is reference to some earlier work in MATLAB, programming or other types of software that make this activity easier

Parent code: Challenges using MATLAB – Students have some difficulty using MATLAB

Child code: Students frustrated with an aspect of the tool – There is a reference to some level of frustration with using MATLAB in this activity

Child code: Students frustrated with parameters, values – Students have difficulty with manipulating parameters, obtaining certain values for the activity, etc.

Child code: Students did not understand what they were doing – Students appear not to understand one or more aspects of the MATLAB assignment

Parent code: Relevance to other courses – There is evidence that what they are doing for this activity connects to one or more courses that they have taken

Parent code: Enjoyment/engagement with MATLAB – Students are described as having a good time and/or being engaged with MATLAB

Parent code: Going “deep” with MATLAB; exploring MATLAB in depth – Students seem to go beyond just the activity’s requirements to unpack MATLAB’s “black box” or to see what else MATLAB can do

Parent code: Less of an inclination to explore/engage with MATLAB in depth – Students only engage with MATLAB in a cursory way “on the surface”

Parent code: Additional resources needed to make activity more meaningful – There is evidence that more support or resources are required to make this a more meaningful exercise for students