An Investigation of Undergraduates' Computational Thinking in a Sophomore-Level Biomedical Engineering Course

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Abstract— **This research study presents our work focused on studying the development of introductory computational thinking in undergraduate biomedical engineering students. In response to the growing computational intensity of the healthcare industry, biomedical engineering (BME) undergraduate education is starting to emphasize computation and computational thinking. Computational thinking is a way of thinking that uses concepts and methodologies of computing to solve problems in interdisciplinary and multidisciplinary subjects. In broader terms, computational thinking is not only associated with using computational tools but also with the thought process of solving a problem by data representation, problem decomposition, and algorithm design. Despite being so important, there is little research work or information available on the development of computational thinking in BME undergraduate students. Our research focuses on how BME undergraduate students develop computational thinking skills while performing group activities related to problem-solving. In order to conduct this study, we incorporate a teaching methodology that prompts computational thinking in a thermodynamics course being taught at a public mid-western university to approximately 120 sophomore students. We observe classroom activities involving analytical problem solving followed by pseudo code generation for computational coding. In order to investigate computational thinking, we collect classroom observations of small groups of students as they come up with a solution to an analytical problem with each other. We complement the observation notes of the classroom activities with follow up semi structured interviews with individual students from five groups. Thematic analysis of the student interviews is used in order to analyze student responses towards the incorporation of computation intensive teaching methodology. This Work in Progress helps us expand our understanding of computational thinking development and the challenges involved in performing computational thinking activity in BME undergraduate students.**

Keywords—thermodynamics, computational thinking.

I. Literature Review

Thermodynamics is a fundamental course required by biomedical engineering students. This course helps students gain an understanding of laws of thermodynamics, energy exchange processes, and design mass/energy-balance equations. thermodynamics is a discipline with an exceptionally wide range of applicability. In the long run, this course also helps the students grasp the reasons and dynamics of current global energy crisis problems. However, despite its importance, it is reported by [7] that thermodynamics undergraduate students struggle with problem-solving in class because they 1) do not properly learn thermodynamics concepts 2) fail to recognize and combine thermodynamics concepts.

Computational thinking (CT) is defined as “the thought processes involved in formulating problems and their solutions so that the solutions are represented in the form that can be effectively carried out by an information-processing agent’’ [1]. CT has been described as an essential skill that everyone should learn [2]. Despite its importance, many students in life sciences are often weak in computing skills and tend to avoid computing-orient activities, one of the potential reasons is Engineering students, as compared to computing-related majors, are not traditionally introduced to computing in the context of authentic learning experiences [3]. There is a need to understand the challenges faced by students while solving a computational thinking activity.

An operationalized framework for defining CT in programming courses is proposed by [5] where CT is condensed into nine general components. These components are abstraction, patterns, decomposition, algorithms, data (collection, analysis, and representation), parallelism, iteration, simulation, testing and debugging. However, there is a need to formally identify CT skills that are practiced in non-programming domains.

II. Research Questions

Question 1: What are the challenges faced by students during a computational thinking activity in a thermodynamics undergraduate class?

Question 2: In a thermodynamics problem, what aspects of computational thinking are observed?

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III. DATA COLLECTION AND ANALYSIS

Research in engineering education has successfully drawn upon the inquiry method of Artifact based interviews as a successful method of eliciting new meanings not possible through traditional interview techniques [6]. It is also observed that the artifact-based interviews are used as a methodology to assess activities involving CT [8]. Artifact-based interviews have an advantage for the interviewer as well as the interviewee. It provides a way for interviewees to describe their artifacts and provide the interviewer with visual hints to ask follow-up questions in order to get an in-depth understanding of the CT activity.

We observe a classroom activity involving analytical problem solving followed by pseudocode generation for computational coding. Classroom observation is followed by Artifact-based semi-structured interviews with the group leaders. Five interviews were conducted within 48 hours of class activity. There were five (N = 5) interview participants in this study. All participants were sophomore majoring in BME at a large midwestern university. Informed consent was gathered from all participants as part of the IRB approved procedures. As part of the interview process, students were asked to bring their notes from the classroom activity that they felt had required them to use computational thinking. The purpose of using the notes during an interview was to provide a context for the discussion. Students could point to specific tasks they underwent when completing the activity and describe the steps or phases of the computational activity and the challenges they faced while performing the activity in the group. Artifact elicitation interview transcripts were analyzed deductively to generate themes.

Activity description: for the purpose of identifying components of the computational activity and challenges faced by students while performing a computational thinking activity in thermodynamics course a class activity of "Countercurrent energy flow problem" was selected which is a closely connected with the 'logical' process of Computational Thinking. In this activity, students were solving for the heat exchange equation for the countercurrent flow problem. Students work with separate streams for the entropy balance equation. The resultant equations are later coded to view dynamic results.

Class observation: Classroom observation of CT activity was guided by the following questions:

- What challenges occurred during problem-solving in a group?
- What were some of the distractions the students faced?
- How did the students break down the problem? Or What was the flow of problem-solving?
- Could the students find similarities or characteristics that some of the problems done in class share with the current problem?
- What are note-taking patterns in the group (do students take few notes, write down everything, write down what instructor puts on board, copy each other's notes in order to keep up with lecture)?
- What challenges occurred during coding the equation?

Interview protocol: Artifact elicitation interviews ranged in duration from 15 to 35 minutes. The interview protocol was developed for student's problem-solving experience in groups. The following questions were asked during the interviews.

- What is the problem? How and why did you solve it?
- How did you get started with solving the problem? What happened when you got stuck?
- Tell me about your experiences with working in a group on problems like this one in class?
- Is there anything else you would like to say about your problem-solving experience?

IV. FINDINGS AND DISCUSSION

The classroom activity was observed for the challenges and distractions the students were facing while problem solving and modelling. It was observed that the students have difficulty with mathematical equation modeling, students were getting stuck deciding which variable or constants are used for the right equations. The classroom observation is complemented with responses from the follow up interviews in order to reach a substantial finding.

Finding 1: "Applying mathematical concepts (derivation, integration, and substitution) during modeling is the most challenging part for students in thermodynamics"

The major hurdle which students faced in this computational activity was students having difficulty with applying mathematical operations to the thermodynamics problems. For example, one of the students said, *"the biggest challenge I would say would be in the math, especially making the derivations and things … that the professor combined in the previous problem, but you weren't sure that they're supposed to be combined in this problem since the flow's [are] different [directions]."*

This student indicated having difficulty in application of the derivatives to the modeling process. Another student shared a similar difficulty in deciding how to apply calculus to a thermodynamics problem.

The student had confusion regarding assessment of the equation on which derivation should be applied; *"I remember I got stuck at a spot where I was trying to do a defined integral with T1 [Time 1] and for some reason today in class it was a different setup [the instructor] said to do a like an undefined integral where you don't give bounds"*. The student highlighted difficulty in understanding how to apply boundary conditions to the model through the application of an undefined or defined integral.

Other students described issues in understanding how different physical elements of the thermodynamic problem might be represented in a mathematical model. As one student shared, *"a lot of the issues we faced came from, ... like what might represent what…so like you have like several different masses that are then represented by a different mass. And so things start to get mixed up very easily"*.

Our first finding suggests students face major challenges in developing analytical solutions that represent the thermodynamics problems before developing a code. This problem in abstraction and problem decomposition is similar to what we had observed in [9]. Classroom observations and student responses also report out difficulties with application of mathematical concepts such as derivation, and integration. These issues were compounded by non-computational thinking difficulties in solving mathematical processes and apprehension of mathematical notation.

Finding 2: "The observed CT competencies in thermodynamics class activity are found to be data analysis, abstraction, algorithm (equation modeling), simulation, testing and debugging."

Groups had different problem-solving approaches. Nine CT competencies are adapted from [5]. The observed problem-solving approaches are decomposed to find relevant corresponding competencies as mentioned in [5]. The identified competencies are not common in each identified approach. However, our findings indicate the set of CT competencies identified from multiple problem-solving approaches.

The students were observed to be following a process of solving the problem in a step by step procedure as done in previous class for a similar problem. All the reported and observed problem solving approaches were analyzed. As a result, two approaches of problem solving emerged out as reported in Table I and II. These approaches were similar to backward and forward problem-solving approaches as mentioned [11]. Our findings suggest that the following components are present in a particular CT activity carried out in a thermodynamics class data (analysis and representation), algorithm (equation modeling), simulation, testing and debugging.

TABLE I. PROBLEM SOLVING: FORWARD APPROACH

Participant Response Quote	***Identified CT Competency***
"So I started by drawing it out just to like get a visualization of like what it would look like? " *"I guess technically we start with drawing the picture first"* *"So I started by drawing it out just to like get a visualization of like what it would look like? Especially because it's easier to look at when we look at it closer part of the pipe. "*	**Abstraction & Problem Decomposition**
"then I did the mass balance from there…..then I did the energy one, because it was also at steady state it like followed where like accumulation is equal to zero. " *"like we use Pseudo code to kind of like take what we know and start beginning to translate it into like what we think can be like a functional code. And so it's kind of like the bridge between like us thinking very abstractly in terms of like python syntax and us thinking very like, um, step by step in terms of just like actually writing out a solution"*	**(Equation modeling) Algorithm**
"in order to solve mathematically, this course uses coding to computationally solve our mathematical process. Especially using outputs such as graphs."	**Simulation Testing and Debugging**

TABLE II. PROBLEM SOLVING: BACKWARD APPROACH

Participant Response Quote	***Identified CT Competency***
"the way that I solved the counter current problem was I saw how unique the graph was for the concurrent graph and I wanted to see what the graph would look like for the countercurrent. So I used Google to see what the picture of the output of the graph from the coding would look like. And I actually did it kind of backwards."	**Data Analysis**
" I used, I solved the code before I solved the math and I made my graph match the one from online cause it's a thermodynamic, um, kind of basis. "	**Simulation Testing and Debugging**
"So we modeled it off of the professor's original example and then we knew since the streams were different directions and all the other variables were similar except for the flow direction, that it's probably just a matter of a sign change. So we modeled a lot of it off of his previous example."	**(Equation modeling) Algorithm**

V. LIMITATIONS

There were several limitations in this study. The major limitation was the single-artifact design, and single class activity coverage [10]. Because of limited time, the activity was performed for a single problem solved during the class. In future work we plan to address this by observing multiple computational thinking problems or activities from the class. Another key limitation is that artifact-based interviews take place after the activity and students may forget crucial details from the class activity. The use of student notes as an artifact to aid student's memories may cause a greater focus on aspects of the problem-solving process that are written down and may miss important parts of problem-solving within the group that takes place verbally. Finally, this study was limited by the size of the sample population. We feel that our interview pool is appropriate for this work-in-progress stage. We attempted to ensure that our data collection was representative of the class by interviewing subjects from different class activity groups.

VI. FUTURE WORK AND RECOMMENDATIONS

Our preliminary findings indicate that students have two different approaches of CT, A forward or a backward CT process approach when it comes to solving a specific computational activity in a thermodynamics class. The components of CT process in a thermodynamics specific activity are found to be abstraction & decomposition. and analysis, equation modeling, simulation, and testing and debugging. More over our findings indicate that the most challenging aspect while performing a CT activity in a thermodynamics class is difficulty in applying mathematical modeling to a thermodynamics problem.

Our findings are based on one computational activity, we plan to study more activities from thermodynamics in order to strengthen our findings regarding the computational components. A similar approach to understand how students perform computational activities in core biomedical engineering or other engineering classrooms is recommended in order to identify learning patterns and CT components. Additionally, we plan to study group dynamics while they perform CT activities in thermodynamics classroom as our classroom observations depict interesting aspects on how group interaction can help overcome the challenges students face in CT activities.

ACKNOWLEDGMENT

This material is based upon work supported by the National Science Foundation under Grant # 1830802. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

REFERENCES

[1]. J. Wing, "Research notebook: Computational thinking—What and why". *The Link Magazine*, pp. 20-23, 2011.

[2]. J. Lockwood, & A. Mooney, "Computational Thinking in Secondary Education: Where Does It Fit? A Systematic Literary Review," *International Journal of Computer Science Education in Schools*, *2*(1), n1, 2018.

[3]. A. J. Magana, M. L. Falk, C. Vieira, & M. J. Reese Jr, "A case study of undergraduate engineering students' computational literacy and self-beliefs about computing in the context of authentic practices," *Computers in Human Behavior*, *61*, pp. 427-442, 2016.

[4]. J. Fagerlund, "A Study on the Assessment of Introductory Computational Thinking via Scratch Programming in Primary Schools," In *Proceedings of the 2018 ACM Conference on International Computing Education Research* pp. 264-265, ACM, August 2018.

[5]. T. Lowe, & S. Brophy, "An operationalized model for defining computational thinking," In *2017 IEEE Frontiers in Education Conference (FIE)*, pp. 1-8, IEEE, October 2017.

[6]. E. P. Douglas, S. S. Jordan, M. Lande, & A. E. Bumbaco, "Artifact elicitation as a method of qualitative inquiry in engineering education," In *2015 122nd ASEE Annual Conference and Exposition*. American Society for Engineering Education, 2015.

[7]. N. Dukhan, "Framing Students' Learning Problems of Thermodynamics," In 2016 *123rd ASEE Annual Conference & Exposition*. American Society for Engineering Education, 2016.

[8]. K. Brennan, & M. Resnick, "New frameworks for studying and assessing the development of computational thinking," In *Proceedings of the 2012 annual meeting of the American Educational Research Association,* Vol. 1, p. 25, April 2012.

[9]. A. Madamanchi, M. E. Cardella, J. A. Glazier, & D. M. Umulis, "Factors Mediating Learning and Application of Computational Modeling by Life Scientists," In *2018 IEEE Frontiers in Education Conference (FIE)*, pp. 1-5. IEEE, October 2018.

[10]. R. K. Yin. *Case Study Research: Design and Methods*. Thousand Oaks, California: Sage Publications, 2014.

[11]. D. Grieser, "General problem solving strategies: Similar problems, working forward and backward, interim goals". In Exploring Mathematics: Problem-Solving and Proof, 1st ed. Cham, Switzerland: Springer, 2018, pp 139-156.