# Assessing Climate Literacy in Engineering Undergraduate Students Through Simulation-Based Learning

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***Abstract*—This full research paper assesses the climate literacy of engineering undergraduate students via simulation-based learning. Climate change is listed as one of the global challenges of the United Nations global issues humanity faces today. The impacts of climate change are global in scope. Rising sea levels and an increased risk of flooding are among the chief concerns faced by nations. This, in turn, has become a threat to global food production which can negatively impact all lives. Therefore, it is important to develop climate literacy by understanding how climate influences us and society at large and how we, in turn, influence the climate. Climate literacy has taken on renewed importance in recent years with the United Nations and numerous national governments employing coordinated efforts to bolster climate education. As such, there is an immediate need for the development of climate literacy as this would help to increase awareness of climate consciousness in society. This study focused on characterizing the climate literacy of undergraduate engineering students as given by the Global Learning VALUE rubric. The students were exposed to climate modeling and simulation exercises using the En-ROADS climate change solution simulator. Students worked in teams and reflected on ways to mitigate climate change and have a best-case scenario that aims to lower the global temperature by 2 degrees Celsius. As there is a great emphasis on integrating education for sustainable development in higher education institutions, this study specifically focuses on using simulation tools as a technological device in classrooms to inspire young engineers to combat global climate challenges. This study aims to create and increase global climate change awareness among young engineers and give them scientific tools to explore strategies for tackling the climate change problem by creating a sustainable environment.**

**This manuscript details a mixed-methods approach guided by the following research questions: i) How can the climate literacy of engineering students be characterized using the Global Learning VALUE rubric, specifically through the use of a simulation-based learning tool? ii) What were the strategies proposed by the students to combat climate change? The results suggest that climate simulations can be valuable tools in exposing students to climate literacy while also having the ancillary benefit of introducing variables that they originally may not have considered. The analysis of the student reflections and proposals using the Global Learning VALUE rubric revealed that students demonstrated a high level of personal and social responsibility and understanding of the global system. Students also demonstrated a good understanding of global awareness. They were able to understand the problems from various perspectives and were able to apply their knowledge to propose feasible solutions to the problem.**

**Keywords— Climate literacy; engineering undergraduates; En-Roads; climate change**

## I. Introduction

The United Nations emphasizes climate change as one of the most crucial global challenges [1]. While climate change mainly refers to the long-term shifts in temperatures and weather patterns, it can adversely impact our food production, access to clean water, and our health, and it can also result in heat waves which in turn lead to rising sea levels causing severe floods [2], [3], [4]. Since the effects of climate change are global in nature, understanding the climate's influence on us and society and our influence on climate is essential, and this is known as climate literacy [5]. Climate literacy has recently taken on renewed importance with the United Nations, and numerous national governments have coordinated efforts to bolster climate education [6]. Research shows an ever-widening gap between the general public and the scientific community regarding climate change facts [5]. Consequently, there is an urgent need for the development of climate literacy as this would help increase awareness of climate consciousness in society. Therefore, this could offer a potential solution to this global challenge. In addition, climate literacy would help raise scientifically informed and responsible decision-makers about global climate change.

The climate literacy movement aims to equip the general public with the knowledge and techniques to identify credible information about climate change and effectively communicate information about the same [6]. There are some potential approaches used for climate literacy through climate education. One approach to promoting education on the science of the climate system was by structuring a 3D interactive digital game, and another approach recommended integrating relevant knowledge from the social sciences [6], [7], [8], [9]. Yet another method recommended using an open-access online simulation tool called En-ROADS, which provides policymakers, educators, businesses, the media, and the public with the ability to test and explore climate solutions [10]. Using visualizations and simulations as part of climate education has generally resulted in increased student interest and conceptual development [11], [12]. En-ROADS, a well-known simulation model, was used in over 125 countries with more than 165 thousand registered participants, through 5950 workshops [10]. This study focuses on using the simulation model of En-Roads to investigate the effects of various

factors and their implications on global warming. En-ROADS is an interactive tool for simulating the long-term impacts of policy actions on global warming. This includes policies affecting energy supply, energy efficiency, carbon emissions prices, land use, and other factors that can reduce greenhouse gas emissions [13]. This simulation tool allows its users to investigate the impact of about 30 policies such as pricing carbon, electrifying transportation and buildings, as well as the effect of improving new technologies for carbon removal on hundreds of outcomes like energy prices, temperature, air quality, and sea level rise [10]. The simulation tool allows users to set up their strategies on energy supply such as coal, oil, natural gas, bioenergy, renewables, nuclear, new zero-carbon, and carbon price. In addition, they can also take action by making changes to transportation, buildings, and industry options by intensifying energy efficiency and electrification, as well as population and economic growth. Lastly, users have options to impact the land, food, and industry emissions via their impact on deforestation/ afforestation and reducing the use of methane and other gases in addition to supporting technological developments on carbon removal techniques. As En-ROADS is an open-access, cloud-based, and user-friendly tool, we used this tool to offer our students to combat climate change by using this climate solution simulator.

This transdisciplinary learning experience has yielded the following key outcomes in terms of: a) contributing to creating awareness about global climate change for sustainable environments; b) aiding students in becoming climate-conscious and helps them develop competencies in global learning; c) enableing students to have a better understanding of complex systems and improves their critical systems thinking skills; d) facilitating the exploration of strategic solutions and policy interventions.

This study utilized the lifecycle sustainability assessment (LCSA) framework as its guiding theoretical framework. LCSA builds off of the lifecycle assessment framework (LCA). LCA refers to the process of analyzing and assessing the impacts of a product or process on the environment [14]. The framework involves defining goals, performing an analysis of inventory, assessing the impact, and finally performing an improvement assessment.

This inquiry details a mixed-methods approach guided by the following research questions: i) How can the climate literacy of engineering students be characterized using the Global Learning VALUE rubric, specifically through the use of a simulation-based learning tool? and ii) How do strategies proposed by students to combat climate change align with the lifecycle sustainability assessment framework?

## II. Theoretical Framework

Lifecycle sustainability assessment (LCSA) was chosen as the guiding theoretical framework for this study as it allows for incorporating systems thinking into the process of evaluating the impact a product has on its environment throughout its entire lifecycle [15]. This covers activities including but not limited to its production, distribution, utilization, and maintenance [16]. LCSA much like lifecycle assessment (LCA) can be used as a tool to compare and contrast impacts on the environment in terms of inputs and outputs over the lifecycle of a product [17]. It begins with the process of defining goals followed by an *inventory analysis* where calculations are performed to evaluate the balance of the system in terms of material and energy [14]. Then an *impact assessment* is performed where the environmental impacts of the product or system are characterized and evaluated. The final step is referred to as *improvement assessment* the aspects with the most positive environmental impacts are identified. LCA employs the process of decision analysis to develop environmental regulations and laws.

The lifecycle sustainability assessment (LCSA) also incorporates social lifecycle assessment (SLCA) and life cycle costing (LCC). SLCA evaluates the positive or negative social and economic impacts of products over their lifecycle [18]. LCC "…seeks to optimize the cost of acquiring, owning, and operating physical assets over their useful lives by attempting to identify and quantify all the significant costs involved in that life…" [19]. LCA on its own doesn't account for cash flows nor does it evaluate the social performance of products or solutions. This is addressed by incorporating LCC and SLCA [20]. LCSA has been successfully implemented in the domains of agriculture, energy, transportation, construction, logistics, and manufacturing [20].

## III. Methods

In the subsequent paragraphs, we will discuss the participants, the context of the study, and the process for data collection and analysis. The study used a mixed methods design to analyze the data.

### *A. Participants, Learning Design, and Context*

This study focused on an undergraduate-level system thinking course offered in the Spring and Fall semesters of 2022, with a total of 77 students and 16 teams. Most of the students were in their final year of university and were pursuing an engineering degree. In addition, before conducting the study, approval from the university's Institution Review Board was obtained with the IRB protocol code: IRB- 2022-254. Pseudonyms were used for the students to protect the confidentiality of their responses. 25 of the students were female, and 57 of them were male. The ages of the students ranged from 19 to 22 years.

The learning environment of this systems thinking course was grounded in a project-based learning (PBL) approach. PBL is a student-centered pedagogy that requires students to work on a project for an extended period to explore and respond to a global challenge as a complex system problem [21], [22].

Students first described and understood systems and systems thinking from engineering, biological, physical, and social scientific perspectives [23]. They explained the fundamental concepts of systems methods and models with applications to real-world problems. Then, they developed proficiency in applying computational modeling to interpret the behavior of complex systems, specifically on global challenges. Finally, they applied concepts and tools of systems science to develop comprehensive policies/solutions/strategies for the complex system problem they were focusing on. Students in this class first explored and extended their knowledge about global warming and its effects and causes. In addition, they learned and tested the new simulation tool En-ROADS during and outside of the classroom by doing individual experiments. Then, they

brainstormed about the ideas and possible feasible scenarios for the target temperature using their prior knowledge to guide them in the process. Furthermore, they investigated various parameters and their impact on global warming to find an optimized solution for the problem as a team. They decided on the best scenario by evaluating the actions and outcomes in the En-ROADS simulation model.

Figure 2 shows a sample from Team 3 of their final actions using the En-ROADS climate solution simulator tool. Finally, they presented the findings and interpreted the solution to the global warming problem [24], [25]. While students were working on all these steps, they were asked to think of this challenge as a complex system problem. Therefore, using systems thinking was highly encouraged. While students were limiting global warming to the targeted 2°C anomaly, they were asked to preserve and create a healthy economy, promote equity, protect the environment, and be realistic. Finally, students were asked to reflect on their feelings as emotions, hopes, and personal actions. Figure 1 shows the stages in the study done in each class period of 75 minutes on each step.


**Figure 1.** Stages in the study for each class period of 75 minutes.


**Figure 2.** A sample from Team 3's simulation model for the climate solution using En-Roads.

## B. Data Collection and Analysis

Data was collected from 77 students for this study. The students worked on these simulations in teams of four to five members. Therefore, a total of 16 proposals were analyzed using the LCSA framework. The data was analyzed using a mixed-method approach [25], [26]. The Global Learning VALUE rubric developed by The Association of American Colleges and Universities (AACU) were used to score the proposals of the students [27]. The Global Learning VALUE rubric focus on global learning and engagement of the students on the following constructs; these are *global self-awareness* (ability to think systematically and understand the interrelationships between self-local and global communities), *perspective taking* (ability to understand own and other perspectives), *cultural diversity* (ability to learn and appreciate cultural diversity and understand it's value to solve global problems*), personal and social responsibility* (ability to make informed decisions and holding oneself accountable when solving some environmental or global problems), *understanding global systems* (ability to understand the role of human organization and action on global problems and making informed decisions to solve them), *applying knowledge to contemporary global contexts* (ability to apply knowledge to solve global problems). The rubrics have four levels, 1 being the lowest and 4 being the highest. Moreover, to ensure the trustworthiness of the scoring process, the student proposals were scored by two raters independently, and then they met and discussed their scores. The discussion helped the raters to understand the scoring process. In the next reliability percentage was calculated as 86% match. For conducting the qualitative analysis, we used thematic analysis [28], [29].

The Lifecycle sustainability assessment (LCSA) model was used as a framework for conducting the analysis. We specifically used deductive thematic analysis to analyze the data. The constructs of the LCSA model served as the pre-defined themes for the analysis. The constructs of LCSA are *goals and scope definition, life cycle inventory, life cycle assessment,* and *interpretation*. To conduct the analysis, each student proposal was read and the statements that matched the constructs of LCSA were mapped accordingly.

# IV. Results

## 1. Rubric Results

The teams focused primarily on optimizing energy use to achieve the goal of 2 degrees Celsius and below. In order to answer our research question 1, the reflections of the teams were scored based on the Global Learning VALUE rubrics [27]. The results are presented in Figure 3.

Based on the rubrics scoring, we identified that student teams demonstrated an intermediate level of *global self-awareness*, meaning they could assess the impact of their own and others' actions on climate change. For example, Team 3 discussed the impact of optimizing the energy resources and its long-term impact on earth's climate *"Starting in 2022, we can moderately subsidize renewable energy and bioenergy, while highly subsidizing nuclear energy. As people move towards these energy options, we will then increase the carbon price from $0 to $125/tonne of CO2 from 2025 to 2035. This will help pay for the subsidies placed beforehand. While existing technologies continue to pave the renewable energy phase, there are plans to discover cheaper New Net-Zero-Carbon fuel."*

Students also demonstrated an *intermediate level of perspective-taking, meaning students focused on cultural, ethical, and economic dimensions* while working on the solution for climate change. For example, Team 4 discussed the results that they obtained from the simulation and shared how the policies can impact the economies of developed and underdeveloped nations.

*"According to our simulation, we have an economic growth rate of 2% every year. Although developed countries like the United States may follow this growth rate by 2030, developing countries may not follow a similar growth rate. According to the Economic Times, "India is poised to grow at 7-8% over the next decade" (Sharma), which is more than*

*triple the amount of growth rate that we have in our simulation. This simulation may prove successful in developed countries but will stunt growth in developing countries.*

Students showed an emerging level of competence in *understanding cultural diversity* as they were able to compare developed and underdeveloped countries when they were discussing their solutions, for example in the quote below, team 5 described the winners and losers of the new climate policies.

*"The biggest winners would be environmental agencies and corporations pushing for electricity like solar, wind, and nuclear factories as well as their investors but also the more developed countries. The biggest losers would be the oil and gas companies, large utility companies as well as less-developed countries experiencing high population growth."*

Students demonstrated a capstone level of knowledge concerning *personal and social responsibility* and *understanding global systems.* This implies that students were able to make decisions while accounting for social, economic, and ethical considerations. For example:

*"More efficient grid systems also result in lower energy bills for households of all incomes. By decreasing these energy bills, black families, which have the highest insecurity of energy, will be able to push their finances elsewhere rather than in power bills. As a whole, it would cut electric bills by more than $100 billion by 2050, which averages to about $300 per household. This is a large solution in a time where 1 in 3 households struggle to pay off energy bills. Though there are numerous things that can be done at an individual level. Recycling, switching to electric vehicles, powering your home with solar panels are such a few action items for individuals."*

For understanding the *global systems* students demonstrated an in-depth understanding. For example:

*"With energy supply being highly taxed, conflicts over natural gas and oil should decrease worldwide. Since population and economic growth are still on the rise it favors developing nations to continue growing but now in a climate-conscious manner. Higher taxes on oil and gas boosts revenue for all nations, money that can now be used to invest in renewable energy development and subsidizing clean energy. Although change comes at a cost, incentivizing electrification in transportation, buildings and industries will lead to the development of cheaper technologies to mitigate climate challenges."*

Students demonstrated an intermediate level of competence in terms of applying knowledge to contemporary global contexts. Students were able to evaluate multiple perspectives before coming to the final solution. For example:

*"In order for this proposal to be realized, there will need to be a global agreement towards all of these policies. This can be done through education about renewable energy sources (especially nuclear) and a general consensus of promoting electrification, afforestation, and push for new technologies. While third-world countries may not have the best resources to alter the climate alone, a public call to reduce pollution and increase forestation will add to the efforts of reducing global warming. Businesses involved in manufacturing, mining, fracking, and other resource heavy industries need to give back to the Earth through making net-zero carbon impacts. The people, government, and business have to realize the efforts it will take to save the planet. This can be done initially through education, starting in the early years."*

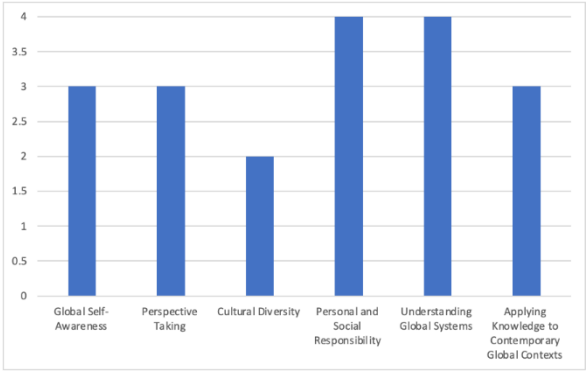


**Figure 3:** Global learning VALUE rubric scores for the 16 teams

2. *Deductive thematic analysis results:*

In order to answer our research question 2, the Life cycle sustainability assessment was used to gain a deeper understanding of the student proposals for climate change. The proposal was evaluated based on the constructs of the life cycle assessment framework, which are goals and scope definition, lifecycle inventory, life cycle impact assessment, and interpretation. The student teams were classified into three categories based on the strategies that they used to mitigate climate change.

*2.1. Goals and scope definition:*

Goals and scope definition is the first part of the lifecycle sustainability assessment as it focuses on the intention of the project and defines the system boundary. In this study, 16 teams used strategies focusing on optimizing energy usage, improvements in electrification in transportation, buildings, and industry, encouraging afforestation, and discouraging deforestation to mitigate climate change. The instructor predefined the goal of the project as bringing down the temperature below 2 degrees Celsius. Students defined their strategies for attaining the desired goal. For example, Team 1 mentioned:

*"The first goal of the Paris Climate goals is to substantially reduce global greenhouse gas emissions to limit the global temperature increase in this century to 2 degrees Celsius while pursuing efforts to limit the increase even further to 1.5 degrees. Our proposal focuses on policies targeting coal, oil, natural gas, and bioenergy which bring in a lot of revenue for a certain few."*

*2.2. Lifecycle inventory:*

The lifecycle inventory focuses on the inputs of the project. Therefore, we focused on students' actions and strategies as their inventory. In the next steps, the teams were able to break their broader goal into sub-steps for example, some of the teams described their sub-strategies as putting high taxation on non-renewable energy resources such as coal, natural gas, etc. so that the consumption of these resources can decrease and propose the use of renewable

energy resources such as nuclear. Here are some sub-steps delineated by Team 2:

*"Highly tax the coal prices, natural gas prices, oil prices and subsidize nuclear and other renewable resource prices."*

Team 3 also described other strategies that could save energy for example cutting on the hours of operation for industries and taxing carbon emissions:

*"We heavily focus on reducing the energy consumption from industries by highly taxing the carbon emission prices. Another idea I had was to also implement a no-production hours policy. This is to reduce the operating hours of industries and in turn, reduce the overall carbon emissions."*

Moreover, some of the teams focused on optimizing transportation by furthering the use of electrification in transportation, buildings, and industry. Here are some suggestions made by Team 6:

*"Technological and electrification advancements will create more employment. Moreover, this will promote equity and a just transition since the wealthiest countries can oversee carbon removal and supply the proper technology to poorer countries for cheaper energy efficiency and electrification. Furthermore, this will protect the environment, since by reducing the amount of carbon utilized, a reduction in emissions will be achieved."*

In addition, some of the teams emphasized developing conscientiousness in global practices such as promoting afforestation and limiting deforestation, investing in technological carbon removal, and incentivizing energy efficiency and electrification in the transportation and industrial sectors. They also focused on improving education on the following issues: a) limiting population growth through education and providing resources for women and b) providing education and resources for those in the agricultural sector regarding deforestation and the benefits of limiting their methane emissions.

*2.3. Lifecycle impact assessment:*

This part focuses on the impact of the inputs from the previous step lifecycle inventory on environmental, economic, and social life. Further, teams also assessed their proposed strategies on economic, social, and ethical parameters.

*A. Economic Impact:*

Some of the teams assess their policies based on the future economic condition for example they did projections for 2030:

*"2030 marks an important year as plans for New Zero-Carbon energy will break through the market. The breakthrough will create a transition, increasing overall energy efficiency, and reducing the need for other non-renewable energy sources (coal, oil, natural gas). Taxes then imposed will continue the transition to environmentally friendly energy supplies as well as transfer jobs from harvesting non-renewables to working on better energy options (nuclear, bioenergy, and the now new zero-carbon). In this transition, there may be a quick dip in the economy, but it will come back as these solutions become the new normal."*

Moreover, from the economic standpoint Team 9 predicted how the economy would be at different points in the future by 2100. They also discussed in what ways the economy would be better or worse.

*"The economy will change slightly in 2022. With the new policies subsidizing/incentivizing electrification and increasing energy efficiency within our infrastructure (transport, buildings, industry), that will spearhead the decrease of greenhouse gas emissions. In terms of the economy, transport will remain somewhat the same but call for the need of more electrified solutions, such as Electric cars, buses, semi-trucks, and trains. With incentivized electrification, this will boost the EV market to a whole new level. This will apply to Buildings and Industry, as electrification will become the new normal. By finding new ways to make our infrastructure energy efficient, companies will save money, allowing a slight increase to economic growth."*

*B. Environmental Impact*

From the environmental standpoint Team 1 foresaw electrification and reduced consumption of fossil fuels as important strategies to save the environment.

*"Our policies strive to move the economy towards electrification and cutting down on the burning of fossil fuels where possible through taxation of coal, oil, natural gas, and bioenergy. Since this is the primary reason driving warming today, targeting to cut burning of fossil fuels will directly reduce the greenhouse gas emissions."*

Furthermore, they justify how the solution proposed can impact the environment positively.

*". ...through the incentivization of reducing greenhouse gas emissions, the industries, corporations, and manufacturers will respond accordingly to cut down their own emissions, and the environmental results will follow."*

*C. Social Impact*

From the social standpoint, students emphasized the importance of the human effort needed to introduce all the concepts and policies and apply them in real life. For example, *"...We do not see our proposal will need human effort to introduce certain concepts and getting used to them."*

The students also described in what ways the proposal fosters equity. For example, Team 4 describes how their strategies will be equally beneficial for developing nations,

*"One of the major considerations of our plan was the impact of coal and oil taxation on developing countries and limiting the negative impacts they might face. While placing a high taxation on coal and oil is an effective way to limit carbon emissions, it severely constrains growth in developing nations. In order to avoid this issue, this project focuses on a light taxation on non-consumable energy sources and a strong incentivization on optimization and electrification of transportation and buildings/industry."*

*2.4. Interpretation:*

Based on the impact from the previous step lifecycle impact assessments, students made conclusions and discussed the limitations and direct applications of the strategies they suggested such as policy making, public awareness movements, strategic plans etc. At the end of their proposal, each team interpreted their findings and assessed in what ways the proposed solution could bring an impact. Team 5 assesses the solutions proposed from a holistic perspective for example the starting point of their assessment is the role

of government, then they proceed to business, then they discuss the role of household and fostering climate literacy.

*"In order for this proposal to be realized, there will need to be a global agreement towards all of these policies. This can be done through education about renewable energy sources (especially nuclear) and a general consensus of promoting electrification, afforestation, and push for new technologies. Businesses involved in manufacturing, mining, fracking, and other resource heavy industries need to give back to the Earth through making net-zero carbon impacts. As businesses make that transition, soon households/residential areas will make that change realizing the cost savings of renewable energy such as solar power. If building codes made solar mandatory, this will further push the public towards this path. Making global warming and environmental effects a part of the curriculum will prepare future generations in solving this issue. Governments have to start this transition through incentives, businesses will comply, the public will follow, then the transition will be finalized by taxing non-renewable energy sources. In doing so, this provides the lasting push for reducing climate change."*

Students also focused on the importance of awareness among the people, government, and businesses to make this dream possible. Team 8 stated the following:

*"The people, government, and business have to realize the efforts it will take to save the planet. This can be done initially through education, starting in the early years. Making global warming and environmental effects a part of the curriculum will prepare future generations in solving this issue. Governments have to start this transition through incentives, businesses will comply, the public will follow, then the transition will be finalized by taxing non-renewable energy sources."*

In doing so, this provides a lasting push for reducing climate change. The strategies discussed and the solutions proposed by the teams demonstrate the effective problem-solving and critical-thinking skills of the student teams.

## 3. DISCUSSION

The study focused on helping engineering students understand the need to become climate literate and develop strategies to mitigate climate change. The results suggest that climate simulations can be valuable tools in exposing students to climate literacy while also having the ancillary benefit of introducing variables that they originally may not have considered. The analysis of the student proposals using the Global Learning VALUE rubric revealed that students demonstrated a high level of personal and social responsibility and understanding of the global system. Students also demonstrated a good understanding of global awareness, were able to understand the problems from various perspectives, and were able to apply their knowledge to propose feasible solutions to the problem.

One of the reasons for students demonstrating generally proficient scores of the constructs of the Global Learning VALUE rubric could be attributed to the majority of students enrolled in the class were in the third or final year of their college education and they already possessed an awareness about how climate change is a global challenge. As such, they may already have been aware of the various initiatives that are being taken by world leaders to mitigate climate change. Moreover, the special emphasis of the systems-thinking class on climate change could be another reason that may have helped students think through feasible solutions to handle the climate change challenge from a holistic perspective.

The analysis of the student proposals using the LCSA framework revealed that all the student groups were able to identify goals and scope, conduct life cycle inventory, assess the impact, and interpret the results. This suggests that the use of climate simulations was effective in enabling students to think strategically about how to tackle climate change [30]. While systems thinking ability was not explicitly evaluated as part of this study, the proposals developed by the student teams all exhibited an appreciation for the multi-faceted nature of climate change and how many interconnected variables must be tackled simultaneously.

### *Implications for Teaching and Learning*

The findings from this study offer significant implications for teaching and learning, particularly within engineering education. First, the integration of simulation-based learning tools, such as the En-ROADS climate change solution simulator, can greatly enhance engineering students' understanding of complex global issues like climate change. These tools provide interactive and practical learning experiences that help students become aware of real-world impacts and understand climate-related challenges. Second, fostering climate literacy through these simulations is crucial for developing future engineers who will play a pivotal role in addressing environmental issues. By engaging with climate modeling and simulation exercises, students increase their climate consciousness and awareness, enabling them to understand the influence of climate on society and vice versa. This knowledge is essential for developing innovative solutions to combat climate change. Third, promoting global awareness and systems thinking is vital. The study showed that students who participated in these simulations gained a comprehensive understanding of global systems and demonstrated global awareness. Educators should emphasize the interconnectedness of global issues and encourage students to adopt a systems-thinking approach, which is crucial for addressing multifaceted challenges. Overall, these implications highlight the need for curriculum developers to prioritize climate literacy and sustainability topics in engineering programs and adopt pedagogical strategies that combine technology, teamwork, and reflection to create engaging and effective learning environments for engineering students.

## 4. CONCLUSION, LIMITATIONS, AND FUTURE WORK

The results of the study suggest that the use of climate simulation tools such as En-ROADS can be effective in enabling students to develop strategies to combat climate change. Furthermore, the solutions developed by the students aligned strongly with the lifecycle sustainability assessment framework. The proposals developed by the students presented different solutions, with the common theme being that they accounted for several socio-economic and cultural variables present in our world.

This study is subject to the limitation that it didn't explicitly measure growth in climate literacy or alignment of solutions with the LCSA framework as a result of the exposure to the climate simulations tool. A longitudinal study could be beneficial in tracking and measuring growth of

climate literacy. This study also did not include the collection of any kind of quantitative data measuring perceptions of or competence regarding climate literacy. The students enrolled in the systems thinking course were all from engineering disciplines and as such the results of this study may not necessarily be generalizable to students from other disciplines. Given the importance of climate literacy owing to the pertinent nature of climate change, future inquiry into the effectiveness of climate simulation tools such as En-ROADS in improving climate literacy could be of great value.

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