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Hydro-Island: Undergraduate Research Modeling an Ocean Thermal Energy Conversion (OTEC) System

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Dr. Tony Kerzmann's higher education background began with a Bachelor of Arts in Physics from Duquesne University, as well as a Bachelor's, Master's, and PhD in Mechanical Engineering from the University of Pittsburgh. After graduation, Dr. Kerzmann began his career as an assistant professor of Mechanical Engineering at Robert Morris University which afforded him the opportunity to research, teach, and advise in numerous engineering roles. He served as the mechanical coordinator for the RMU Engineering Department for six years, and was the Director of Outreach for the Research and Outreach Center in the School of Engineering, Mathematics and Science. In 2019, Dr. Kerzmann joined the Mechanical Engineering and Material Science (MEMS) department at the University of Pittsburgh. He is the advising coordinator and associate professor in the MEMS department, where he positively engages with numerous mechanical engineering advisees, teaches courses in mechanical engineering and sustainability, and conducts research in energy systems.

Throughout his career, Dr. Kerzmann has advised over eighty student projects, some of which have won regional and international awards. A recent project team won the Utility of Tomorrow competition, outperforming fifty-five international teams to bring home one of only five prizes. Additionally, he has developed and taught fourteen different courses, many of which were in the areas of energy, sustainability, thermodynamics, dynamics and heat transfer. He has always made an effort to incorporate experiential learning into the classroom through the use of demonstrations, guest speakers, student projects and site visits. Dr. Kerzmann is a firm believer that all students learn in their own unique way. In an effort to reach all students, he has consistently deployed a host of teaching strategies into his classes, including videos, example problems, quizzes, hands-on laboratories, demonstrations, and group work. Dr. Kerzmann is enthusiastic in the continued pursuit of his educational goals, research endeavors, and engagement of mechanical engineering students.

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Abstract

We are in the midst of a strong shift in climate change awareness in the U.S. The public discourse is swinging from climate denial toward climate alarm. A recent poll by the Yale Program on Climate Change Communication (YPCCC) found that Americans are around four times more likely to be alarmed by climate change than they are to dismiss the science. This is a drastic, and long overdue, shift in sentiment from 2015 poll results where the same two survey categories were almost dead even. As we transition our mindset to combat global warming, we also have to visualize the future of our existing energy systems and infrastructure. Renewable energy is an obvious choice to reduce greenhouse gas emissions, but we need to be thoughtful in our long-term vision of its deployment, including the global availability of renewably derived fuels. Of these fuels, hydrogen may be the most promising in its broad deployment. It has a high energy density (almost 3 times that of gasoline), is readily available, can replace natural gas in existing gas pipelines and can be shipped via hydrogen tankers. Although still in the demonstration phase, hydrogen tankers would provide the capability to efficiently transport hydrogen fuel all over the world.

As hydrogen shipping technologies grow more mature, the door for offshore hydrogen production opens. Hydrogen has the potential to be produced offshore using renewable energy and electrolysis, then transported to ports around the world, effectively creating oceanic Hydrogen Islands. These islands would be capable of supplying hydrogen to onshore facilities via hydrogen tankers but could also fuel the transport ships themselves. A recent study found that 99% of transpacific voyages made in 2015 could have been powered by hydrogen. In an effort to further develop the idea of a hydrogen producing island, a small team of undergraduate students were formed to evaluate the feasibility of renewable offshore hydrogen electrolyzation utilizing an Ocean Thermal Energy Conversion (OTEC) system.

This research is focused on the work of one student in the group who is modeling the Hydro-Island powerhouse; the OTEC system. The energy model was built in Engineering Equations Solver and incorporates thermodynamic, heat transfer and fluid mechanics principles. The student was able to improve her knowledge of concepts in these fields through this research learning project. An OTEC system has a low thermodynamic efficiency (around 4-6%) due to the relatively low temperature difference between the hot and cold thermal reservoirs. In an effort to attain higher efficiencies, a solar pond was incorporated into the OTEC system model. A solar pond is designed to absorb solar energy, thereby increasing the temperature of the hot side of the Rankine cycle. The model compares different OTEC scenarios to find the effect of solar ponds on energy production and system performance. The environmental variables utilized in the model are from Gulf of Mexico water and climactic conditions. The Gulf of Mexico is home to an abundance of abandoned offshore oil rigs which could potentially be repurposed to provide the platform for the OTEC system. The modeling results provide important insights into the system energy production, sizing, efficiency, and pumping needs. Through work on this project, the student was able to improve her knowledge of important engineering concepts as well as be introduced to research and clarify her goals post-graduation.

Introduction

As climate change affects the lives of many around the world, reliable renewable energy is increasingly important. One way to engage engineering undergraduate students in a project that is relevant to their futures is to create a renewable energy research project. As new renewable energy technologies are explored to expand the portfolio of renewable energy, ocean renewable energy is becoming an increasingly researched topic. The ocean is still a largely untapped source of energy. One type of ocean renewable energy, Ocean Thermal Energy Conversion (OTEC), can produce up to 10 TW of power (almost 4 times the power used by the world) without negatively affecting the ocean environment [1],[2]. Additionally, this power source is stable and predictable. Research on this technology is especially helpful for students to learn and apply thermodynamics, fluid mechanics, and heat transfer concepts.

OTEC is an energy technology that harnesses the difference in temperature between the cold of the deep ocean and the warmth of the ocean surface. However, due to the relatively low efficiency of the system, pumping and infrastructure of OTEC causes high initial costs [3]. One way to increase the efficiency of the system is to increase the temperature difference necessary to drive the Rankine cycle. Solar ponds are a technology that can use solar radiation to produce hot water and provide a higher maximum temperature than the warm ocean water.

Solar ponds use a saltwater gradient with high-salinity water at the bottom of the pond and lower salinity water at the top, which prevents the dense salt water from rising to the surface as it heats, effectively reducing vertical convection and trapping high levels of heat in the bottom of the pond [4]. By combining the OTEC and solar pond technologies, the efficiencies of the entire system can more than triple.

In this project, a student researched the feasibility of OTEC-only and OTEC-Solar Pond systems in the Gulf of Mexico to produce electricity which would be used to electrolyze hydrogen. She created a program in Engineering Equation Solver (EES) to model the OTEC only and OTEC-Solar Pond systems of 10 MW and 100 MW sizes to determine the feasibility of these systems. The experience helped to teach and reinforce countless important concepts from thermodynamics, fluid mechanics, and heat transfer. All levels of learning detailed in Bloom's taxonomy were reached through this project for a wide range of concepts, and the student participated in many cycles of the Kolb's experiential learning cycle.

The student also gained experience in the full cycle of a research project, from conducting a literature search to writing a conference submission. By working with her mentor through each step in the research process, the student gained confidence in her abilities to be successful in research. With minimal previous research experience, the student was initially reluctant to commit to the rigors of graduate school research for fear of failure, despite having interest in research. This project's success encouraged the student to choose a research-based master's degree program and provided the confidence necessary to pursue her interests.

The OTEC project provided a unique opportunity for the student to explore and reflect on her interests. A list of potential research areas provided by the mentor allowed the student to narrow down the research area of focus within the broad field of mechanical engineering. Through regular discussions with the mentor and literature review, the student was able to further narrow down her interests and create a proposal for the HydroIsland research project. Through this mentorship, the student determined which field and career path she wanted to pursue post-graduation.

Model Development

Four simulation models of the HydroIsland were created, each for a different scenario: 10 MW OTEC, 100 MW OTEC, 10 MW OTEC-Solar Pond, and 100 MW OTEC-Solar Pond. The OTEC-only models were developed and compared to the OTEC-Solar Pond models, and the two different power output options were chosen to compare the feasibility of a smaller 10 MW vs a larger 100 MW plant. Ammonia was chosen as the working fluid, as it is commonly used in OTEC systems and models. The HydroIsland research project models were created in EES by coding each state of the Rankine cycle and then coding inefficiencies for the system. The states of the OTEC Rankine cycle are shown in Figure 1.

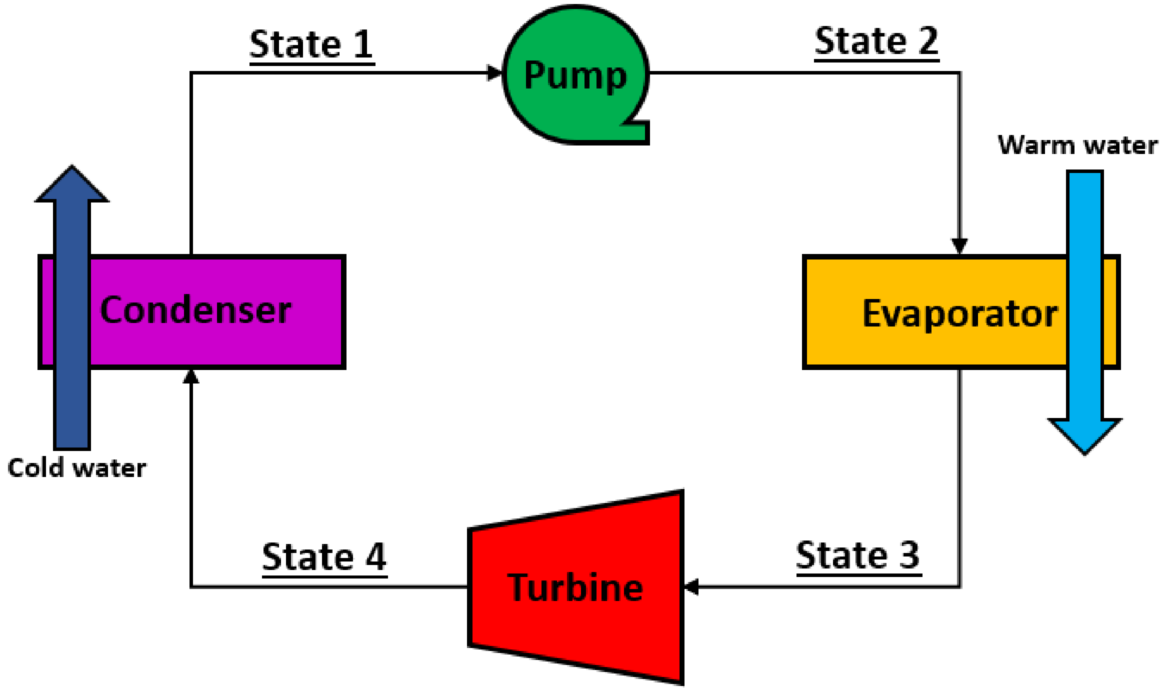


Figure 1: OTEC Rankine Cycle

For simplicity, it was assumed that there is no pressure loss in the condenser or evaporator, and the high and low pressures were determined using a series of parametric tables to optimize the efficiency of the system for each model. The system was modeled under Gulf of Mexico climactic conditions due to the substantial gulf water depths which provide the temperature difference needed to run the OTEC system's Rankine cycle. The climactic conditions were determined using the World Ocean Atlas from the National Oceanographic and Atmospheric Administration (NOAA), which showed the yearly average temperature near the surface of the water (25 m deep) to be 26 degrees Celsius and the temperature at 1000 m deep to be 5 degrees [5]. To account for heat losses in the heat exchangers and piping, a 5ºC heat loss was assumed, matching the heat loss in the NREL Ocean Thermal Extractable Energy Visualization (OTEEV) analysis [6]. The cold temperature for the ammonia used in the models was 10 degrees Celsius and the warm temperature was 21 degrees Celsius.

In addition to an isentropic efficiency of the turbine and pump, five different inefficiency sources were considered to increase the accuracy of the model: power loss due to the cold-water pipe intake head loss, condenser and distribution piping pressure power loss due to head loss, evaporator and distribution piping pressure power loss due to head loss, and ammonia pumping and cold-water pipe friction power loss.

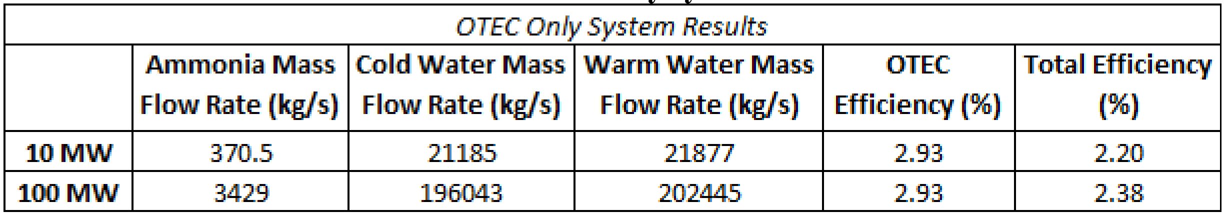
The solar pond models used the warm water temperature from the solar pond instead of the surface ocean temperature. Solar ponds can reach 64ºC [7]. Again, 5 ºC of heat loss was assumed so the working warm temperature for the ammonia was 61ºC. The cold temperature remained the same as the OTEC-only models.

Due to the possibility for differences between the assumptions made in this model and the reality, a sensitivity analysis was also completed to understand how a 10% increase or decrease in various parameters would affect the results of the model.

Simulation Results

General results from the OTEC only simulations (both 10 MW and 100 MW) are shown in Table 1 below.

Table 1: OTEC only system results.

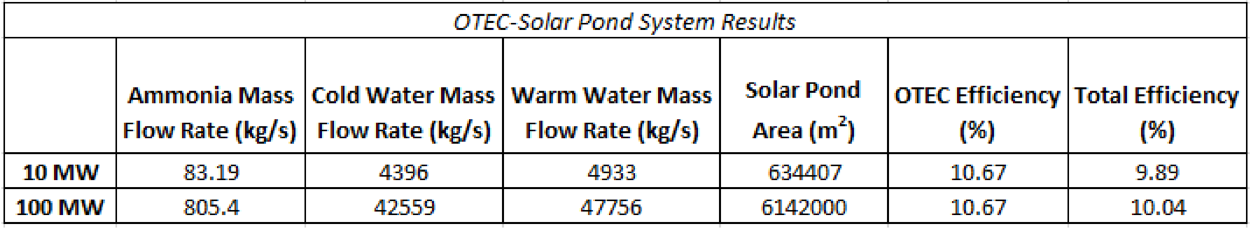


OTEC Only System Results

	Ammonia Mass Flow Rate (kg/s)	Cold Water Mass Flow Rate (kg/s)	Warm Water Mass Flow Rate (kg/s)	OTEC Efficiency (%)	Total Efficiency (%)
10 MW	370.5	21185	21877	2.93	2.20
100 MW	3429	196043	202445	2.93	2.38

General results from the OTEC-Solar Pond simulations (both 10 MW and 100 MW) are shown in Table 2.

Table 2: OTEC-Solar pond system results.



OTEC-Solar Pond System Results

	Ammonia Mass Flow Rate (kg/s)	Cold Water Mass Flow Rate (kg/s)	Warm Water Mass Flow Rate (kg/s)	Solar Pond Area (m^2)	OTEC Efficiency (%)	Total Efficiency (%)
10 MW	83.19	4396	4933	634407	10.67	9.89
100 MW	805.4	42559	47756	6142000	10.67	10.04

A visual showing the disparity between the total losses of each system type is shown in Figure 2, and the overall efficiencies of each system are shown in Figure 3.

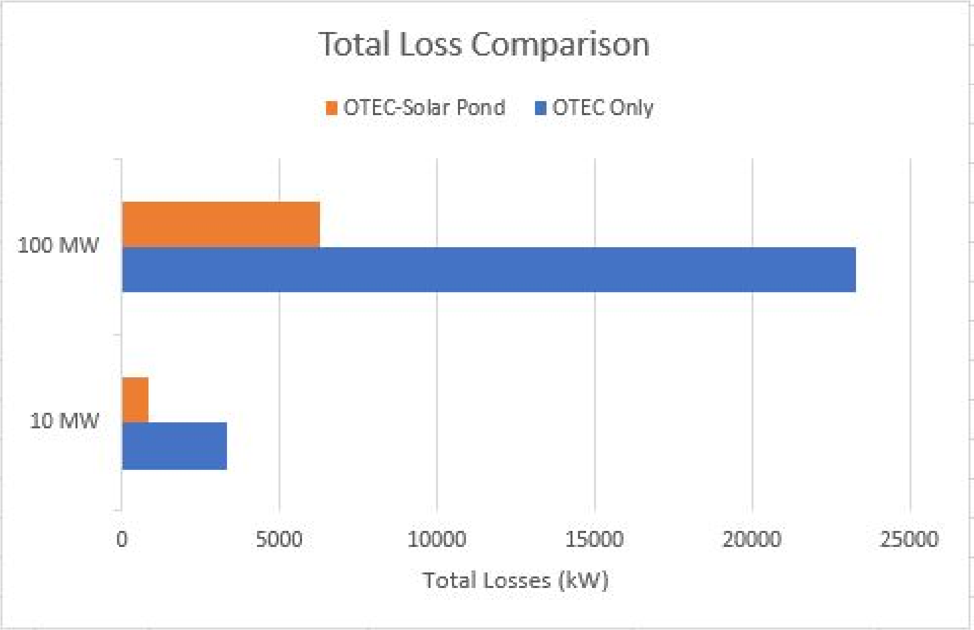


Figure 2: Total loss comparison of all models.

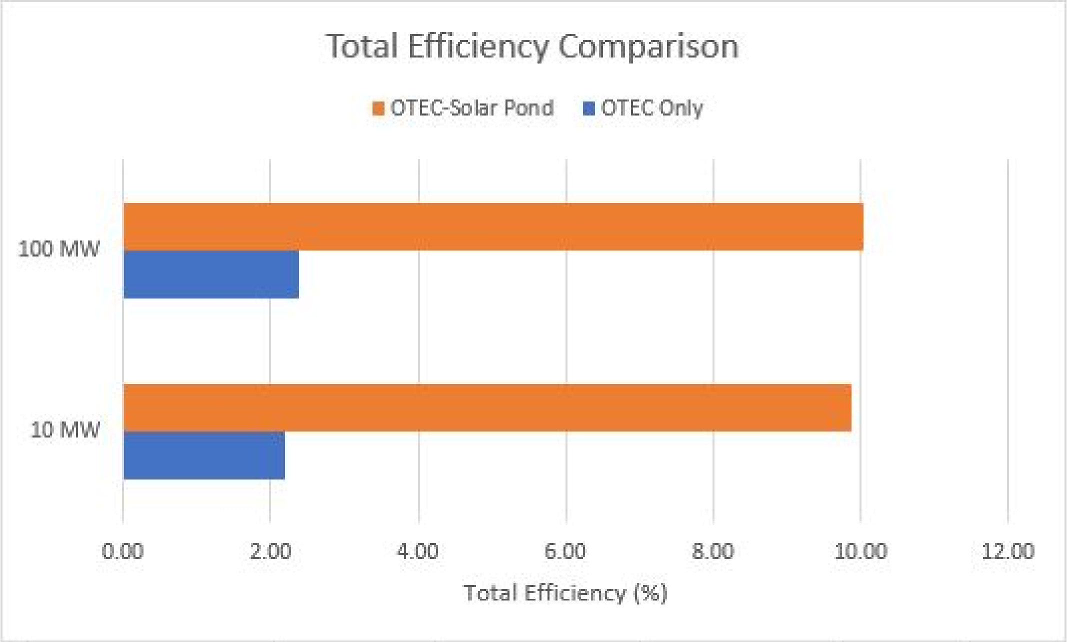


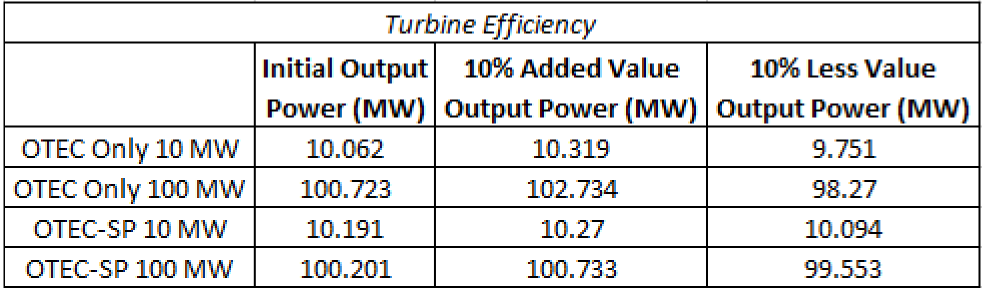
Figure 3: Total efficiency comparison of all models.

Based on Figures 2 and 3, it is clear that the solar pond systems have a much higher efficiency and have much lower losses, due to the smaller amount of seawater that needs to be pumped from the depths of the ocean. However, when looking at the area of solar pond that was necessary to continuously provide the required heat, the 100 MW solar pond may not be reasonable, at 6.14 million square meters (2.37 square miles). This makes the 10 MW OTEC-Solar Pond system the more reasonable choice.

The 10 MW and 100 MW OTEC only systems do not require an area for a solar pond, but they require much more pumping power and greater pipe sizing because the required water flow rates are significantly higher due to the lower efficiency.

A sensitivity analysis of various variables found that the turbine isentropic efficiency and the warm temperature had the greatest change in power output when increased or decreased 10% from the initial value. The turbine isentropic efficiency sensitivity analysis results are summarized in Table 3.

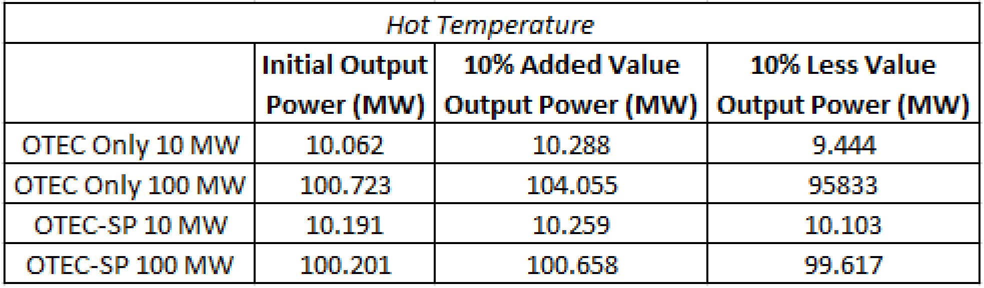
Table 3: Turbine isentropic efficiency sensitivity analysis results.



Turbine Efficiency			
	Initial Output Power (MW)	**10% Added Value Output Power (MW)**	**10% Less Value Output Power (MW)**
OTEC Only 10 MW	10.062	10.319	9.751
OTEC Only 100 MW	100.723	102.734	98.27
OTEC-SP 10 MW	10.191	10.27	10.094
OTEC-SP 100 MW	100.201	100.733	99.553

The warm water sensitivity analysis results are shown in Table 4.

Table 4: Warm water sensitivity analysis results.



Hot Temperature			
	Initial Output Power (MW)	**10% Added Value Output Power (MW)**	**10% Less Value Output Power (MW)**
OTEC Only 10 MW	10.062	10.288	9.444
OTEC Only 100 MW	100.723	104.055	95833
OTEC-SP 10 MW	10.191	10.259	10.103
OTEC-SP 100 MW	100.201	100.658	99.617

An environmental and economic analysis would need to be completed to find which of these systems is most feasible for use in the Gulf of Mexico. Regardless of which system is used, the energy produced needs to be stored or sent in undersea cables back to land. Since the areas of the Gulf of Mexico with 1000 m deep waters and oil platforms are not generally near land, undersea cables would also be expensive. A better option could be to convert the electricity produced into hydrogen fuel through electrolysis to be stored in a hydrogen tanker, but this is energy intensive because of the high-pressure and low temperature requirement for hydrogen fuel storage. Due to the high static pressure in the deep sea, electrolysis at low ocean depths could provide a significant portion of the pressure and reduce the power needed to compress the hydrogen.

Experiential Learning

The HydroIsland research project provided an excellent opportunity to contribute to the student's undergraduate education through experiential learning. All parts of the research process added to and reinforced her knowledge of mechanical engineering.

Bloom's taxonomy, a method of classifying cognitive processes in learning, breaks down learning into a hierarchy of six processes [8]. Initially created in 1956 by Benjamin Bloom and a team of collaborators, Bloom's taxonomy was revised in 2001 by a multidisciplinary group of researchers to put more focus on the actions performed in each category and labelling them accordingly [9]. This action-focused version of Bloom's taxonomy will be the basis for the following discussion. The taxonomy processes, Remember, Understand, Apply, Analyze, Evaluate, and Create are arranged in the hierarchy as shown in Figure 4 below [8]. Educators often use this framework to achieve specific education goals, and Bloom's taxonomy is used in this work as a standard to compare the learning experience of undergraduate research [9]. Through this method of comparison, the student's undergraduate research project engaged the learning process further than any in-class project could have, by reaching all aspects of Bloom's taxonomy across many different mechanical engineering topics.

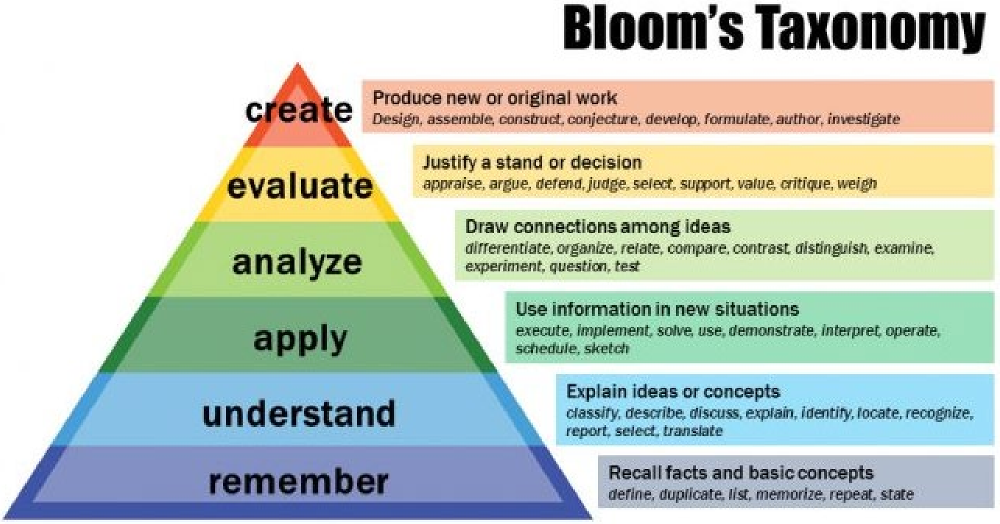


Figure 4: Visualization of Bloom's Taxonomy, courtesy of Vanderbilt University Center for Teaching. Used with permission. [8]

The most basic Bloom's Taxonomy process is Remember, the act of recalling simple facts and concepts [9]. When performing a literature search and setting up her model, the student needed to recall the definitions and concepts of various thermodynamic, fluid mechanics and heat transfer mechanical engineering topics. The main topic, thermodynamics, related very heavily to her engineering thermodynamics class concepts. Concepts such as thermodynamic efficiency, the Rankine cycle, ideal vs real Rankine cycle, mass and volumetric flow rates, rates of heat transfer, work, and power were essential to the OTEC and solar pond technologies, and to even begin this research she needed an established recall of these concepts. Within another important topic, fluid mechanics, she needed to recall fluid flow inefficiencies such as pipe friction head loss, the Darcy-Weisbach equation, Moody diagram, and more. Heat and mass transfer concepts such as heat exchangers, convection, and radiation, were also important aspects of the system modeling. Finally, she learned to recall new topics such as OTEC, solar ponds, and hydrogen production which were researched in her literature review.

The second level in Bloom's Taxonomy is Understanding, the ability to explain ideas or concepts [9]. These concepts were discussed and explained during weekly meetings with her mentor. As part of the special projects course, the student wrote a research proposal and a final paper, both of which incorporated sections that demonstrated her ability to explain ideas and concepts.

The next step is Apply, the act of using information in new situations [9]. The student used her knowledge of thermodynamics, fluid mechanics, and heat and mass transfer to build EES code and analyze models of the OTEC and OTEC-Solar Pond systems in the Gulf of Mexico.

The fourth level is Analyze, the ability to draw connections among ideas [9]. Throughout the project, the student had to draw connections between various concepts and ideas. In the literature search, she had to draw connections and organize the information from the various research conducted on OTEC systems to understand what has been extensively researched and where there might be gaps in knowledge. In the creation of her model, she had to analyze the simulation data to ensure it made physical sense. For example, as part of a check for errors, she always made sure that the thermodynamic efficiency was below the Carnot efficiency. The Carnot efficiency was not necessary to her results otherwise, but the student made the connection that there would have to be an error in the code if the efficiency was above the Carnot efficiency.

The fifth level is Evaluate, the act of justifying a decision [9]. When evaluating the results of the models, she had to decide on the feasibility of each option, and then justify that feasibility. The student also had to justify the various decisions made when creating the model. This moved past many classroom experiences as there were no correct answers for some of the decisions. She had to explore the options and determine which might be most accurate or reasonable for the project. While she justified these decisions in meetings with her mentor, she also spent a long time justifying and updating the model when writing the final paper.

The final level is Create, producing a new or original work [9]. As is inherent in research, the student created an original work. The simulation models, conclusions, and final paper were all original, forcing the student to learn the topics beyond general classroom understanding and become very knowledgeable of the existing literature.

Another learning theory that shows the benefits of the HydroIsland undergraduate research is Kolb’s Experiential Learning Cycle [10]. Created in 1984 by David Kolb, the focus of his theory is that learning experiences with educational concepts are necessary to truly learn and understand the concepts [10]. He developed a four-part learning cycle for experiential learning, with the steps shown in Figure 5.

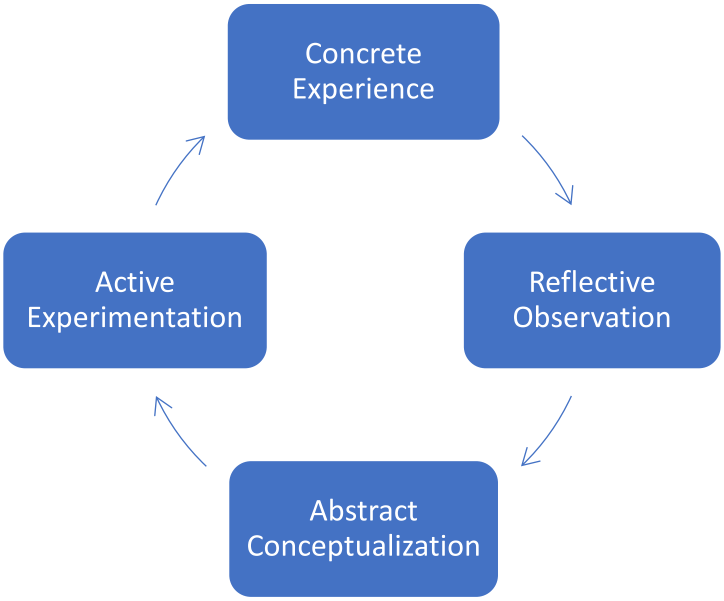


Figure 5: Kolb's Experiential Learning Cycle.

Kolb argues that for effective learning, all four stages of the learning cycle must be performed [10]. In the HydroIsland undergraduate research project, the student engaged in the Kolb experiential learning cycle many times, improving her grasp on the many engineering concepts used in the project.

The first part of the cycle, concrete experience, is encountering or executing a new experience with the concept that will be learned [10]. In building the model, she had a concrete experience with many concepts from thermodynamics, fluid mechanics, and heat and mass transfer. She started with a very simple model of an ideal Rankine cycle. This led into the next part of Kolb's experiential learning cycle, reflective observation, where students review their experience and reflect on it [10]. Each week, the student would review the model before meeting with her mentor. This review process would allow for reflection on ways to improve the model and to determine if there were any simulation inaccuracies that might produce unrealistic results.

The third step is abstract conceptualization, where a new idea or modification to the concepts learned in the experience is determined [10]. Based on areas that were in need of improvement in the model, the student would investigate how to make the model more accurate or realistic. When these improvements were implemented, the fourth part of the cycle, active experimentation, was engaged. Ideas for improvement from the abstract conceptualization were implemented into the model, and thus a new simulation was created [10]. After developing an improvement plan, the student was able to implement changes to the model and conduct a new set of simulation tests to determine if the model results made real-world sense. The technical concepts and techniques learned from this project were further reinforced through this continuous cycle of building on experiences through each iterative process.

Similar to the way the student went through Kolb's Experiential Learning Cycle many times while creating and improving the model, students learning Thermodynamics and Fluid Mechanics concepts could participate in a semester long project. The project could consist of an ideal model of an OTEC system which would provide a base for the simulation project and new classroom concepts could be added to the simulation as the students learn them throughout the semester. For example, the model might start out as an ideal Rankine cycle, and then inefficiencies could be added to the simulation as the students become acquainted with the concepts throughout the semester. Students would then gain a stronger understanding of these engineering concepts by running through Kolb's Experiential Learning Cycle. The students could choose an area within modelling to perform the research, such as comparing OTEC efficiencies for different oceanic locations or nearshore OTEC that uses sea water air conditioning thus providing an individually customizable project experience.

Undergraduate Research Experience

This undergraduate research experience helped clarify the student's post-graduation goals and allowed her to gain confidence in her abilities to succeed in graduate school. Before the project, the student was unsure if she wanted to commit to a research-based master's degree or focus on a professional (non-thesis) master's degree. She also lacked the experience and confidence to truly see her future in graduate research. The student had always had an interest in renewable energy, but there were no undergraduate classes focused on renewable energy in the department, so the student decided to try out research in renewable energy.

A professor in the student's mechanical engineering department, has research experience in renewable energy and offered to start a new project with the student based on her interests. This allowed her the freedom of choosing her own topic within renewable energy and allowed her to focus her interests as far as she wanted without obligations. She chose to study ocean renewable energy and began by performing a literature search that narrowed down topic area. Through weekly discussions and literature search, the mentor and student were able to decide on a combination of synergistic renewable energy technologies, with the idea of re-purposing offshore oil platforms in the Gulf of Mexico to provide the necessary renewable energy infrastructure.

Through this unique opportunity, the student was able to ease into the world of research, with a mentor to help her every step of the way. As stated in the article *Benefits of Undergraduate Research: The Student Perspective*, undergraduate research provides an opportunity for one-on-one mentorship that students rarely get otherwise with faculty members [11]. This opportunity to work with a mentor each week gave the student the time to ask questions, work through issues, and improve her understanding of concepts. Previous to this research, the student found research to be a daunting unknown. After building interest and confidence in conducting a literature search and defining a research project, the student felt ready to work in a more time-intensive and structured manner. Working with her mentor, she wrote a proposal which clearly defined the research goals, expectations, and the timeline. Throughout the research, the student found that her interest and confidence in leading her own research project grew. This cemented her decision to pursue a research-based master's degree and her decision to continue working in the ocean renewable energy field.

Working through the entire process of a research project from the initial literature searches, to conducting research, to writing a conference manuscript, she gained confidence in her ability to succeed in graduate school research. She learned research habits that will be helpful in the future and learned from her errors both through experience and from discussions with her mentor. Graduate school research is still a daunting task, but she no longer has any doubt that she will succeed in writing and defending her thesis.

Conclusion

A HydroIsland research project was developed from initial conceptual ideas to a detailed simulation model of an OTEC system. The project provided an opportunity for a student to gain experience in the research process on a topic that is relevant to today's world and reinforces many concepts in thermodynamics, fluid mechanics, and heat transfer. The project created an experience that reached every level in Bloom's taxonomy and achieved multiple cycles of Kolb's experiential learning cycle. This project also provided the student with confidence in her ability to succeed in a research-based master's degree, helped her learn important research habits through mentoring, and clarify what industry she would like to pursue after graduate school.

Based on Bloom's taxonomy and Kolb's Experiential Learning Cycle theories, the HydroIsland undergraduate research project was a powerful learning opportunity, and deeply reinforced concepts taught in the classroom. Groups of students could be similarly or further impacted by creating original OTEC models investigating new topics and updating them as new concepts are introduced throughout the semester. Thermodynamics and Fluids Mechanics students could potentially create OTEC modeling scripts investigating customizable topics that suite the student's interest and update the model as they learn new concepts in the classroom. Through developing these simulation projects, students can reinforce the concepts they are learning in engineering classes while getting an introduction to the research process. Through this initial glimpse into research, students will discover whether research is right for them, and consequently formulate their future interests and goals.

The HydroIsland models that were developed for the various simulated OTEC systems provide information to inform the feasibility of each system and can be used to guide future design choices and research. Through this project, many areas of future research projects for the HydroIsland concept were identified, such as environmental impacts, economic feasibility, and research in creating hydrogen in high pressure oceanic environments. The researchers plan to leverage the knowledge and experience gained from this project to continue to investigate the conceptual idea of off-shore hydrogen production, while providing a base for future students to conduct research projects that will enhance their education and provide high-level experiential learning.

References

[1] R. Pelc, R. M. Fujita, "Renewable Energy from the Ocean," *Marine Policy*, vol. 26, no. 6, pp 471-479, November 2002 [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0308597X02000453 [Accessed: May 5, 2020].

[2] "Key World Energy Statistics," *International Energy Administration*, 2020 [Online]. Available : https://www.iea.org/reports/key-world-energy-statistics-2020/final-consumption#abstract [Accessed: May 30, 2020].

[3] C. Bernardoni, et al., "Techno-economic Analysis of Closed OTEC Cycles for Power Generation," *Renewable Energy*, vol. 132, pp 1018-1033, 2019 [Online]. Available: https://www.sciencedirect.com.pitt.idm.oclc.org/science/article/pii/S0960148118309595?via%3Dihub#sec1 [Accessed: April 19, 2020].

[4] P.J.T. Straatman, W.G.J.H.M van Sark, "A new hybrid ocean thermal energy conversion–Offshore solar pond (OTEC–OSP) design: A cost optimization approach," *Solar Energy*, vol. 82, no. 6, pp 520-527, June 2008 [Online]. https://doi.org/10.1016/j.solener.2007.12.002. [Accessed: April 30, 2020].

[5] "Annual Temperature [C] (1955-2017)," Ocean Climate Laboratory, *National Oceanographic and Atmospheric Administration*, 2020 [Online]. https://www.nodc.noaa.gov/cgi-bin/OC5/SELECT/woaselect.pl [Accessed: April 15, 2020].

[6] M. B. Ascari, et al, "Ocean Thermal Extractable Energy Visualization- Final Technical Report on Award DE-EE0002664," *Office of Scientific and Technical Information*, 2012. Available: https://www.osti.gov/servlets/purl/1055457 [Accessed: June 5, 2020].

[7] D. B. Sifuna, et al, "Comparison of Thermal Storage Efficiency of Solar Pond with and without a Polyethene Membrane," *International Journal of Scientific and Research Publications*, vol. 4 no. 9, 2014 [Online]. Available: http://www.ijsrp.org/research-paper-0914/ijsrp-p3390.pdf [Accessed: May 30, 2020].

[8] P. Armstrong "Bloom's Taxonomy," *Vanderbilt University Center for Teaching* [Online]. Available: https://cft.vanderbilt.edu/guides-sub-pages/blooms-taxonomy/ [Accessed Feb. 18, 2021]

[9] "Bloom's Taxonomy", Bloom's Taxonomy [Online]. Available: https://www.bloomstaxonomy.net/ [Accessed: Feb. 18, 2021].

[10] S. A. McLeod, "Kolb - learning styles and experiential learning cycle.," *Simply Psychology,* 2017 [Online]. Available: https://www.simplypsychology.org/learning-kolb.html [Accessed: Feb. 25, 2021].

[11] C. Madan, B. Teitge, "The Benefits of Undergraduate Research: The Student's Perspective," *The Mentor: An Academic Advising Journal,* vol. 15, 2013 [Online]. Available: https://journals.psu.edu/mentor/article/view/61274/60907. [Accessed: Feb. 25, 2021].