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Teaching STEM Early-college Students: A New Methodology to Teach Energy Complex Systems

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Teaching STEM Early College Students - A New Methodology to Teach Energy Complex Systems

Abstract:

Teaching thermodynamics and heat transfer disciplines seem difficult for our students. Statistics show that a large number of students fail or drop out or even transfer from STEM-related disciplines to other non-engineering fields, due to the misunderstandings and difficulties encountered during taking fundamental courses such as thermodynamics.

In this article, our aim is to share my experience developing a methodology for early-college students, that addresses particular educational challenges, using visualization-based methods and interviews with knowledgeable personal and experts in the area, to give the students the opportunity to understand the ins and outs of a specific application, without too much math and theory. Once the student has reached a certain level of confidence in their knowledge, we move on to other stages where more theoretical concepts are introduced. Our methodology is based on three tasks: (1) field visits; (2) literature; (3) computer applications; (4) mathematics and science.

In this work, we used the existing campus facilities to introduce students to the systems used to heat the campus. Our aim is to expose the early college students to the installation of the power plant, without focusing on theoretical aspects, thermodynamic cycles, and properties of fluids, but focusing on understanding the functionality of systems, as it comes from the drivers who take care of the power plant. This information accompanies the visits, where visualization is the main explanatory tool, as these installations are generally noisy and it is very difficult to hear the explanation of the various maintenance personnel.

In this article, I will expand on my experience with mentoring STEM early college students to achieve a higher level of understanding of power plants. The aim is to contribute to the preparation of a STEM pipeline in the field of engineering and advanced manufacturing. The pipeline for research and higher education begins specifically at an early age, where students are encouraged to peruse STEM-related programs. Our programs are mainly oriented toward high school, and early college students and continue through the completion of a college degree in STEM areas.

In this paper, we discuss the project design program from a student's perspective and experience gained in engineering, integration, written, and oral communication. The methodology used to improve the students' understanding of complex problems is also described.

Introduction:

Teaching thermodynamics and heat transfer disciplines seem difficult for our students. Statistics show that a large number of students fail or drop out or even transfer from STEM-related disciplines to other non-engineering fields, due to the misunderstandings and difficulties encountered during taking fundamental courses such as thermodynamics (Loverude et al., 2006; Hake, 1998; N. Mulopa et al., 2012).

At NCAT, I was approached to be a mentor for early college students to guide them through a project related to power plants. The aim of this article is to share my experience developing a methodology for early-college students, that addresses particular educational challenges, using visualization-based methods and interviews with knowledgeable personal and experts in the area, to give the students the opportunity to understand the ins and outs of a specific application, without too much math and theory. Once the student has reached a certain level of confidence in their knowledge, we move on to other stages where more theoretical concepts are introduced. Our methodology is based on three tasks: (1) field visits; (2) literature review; (3) computer applications; (4) mathematics and science.

In this work, we used the existing campus facilities to introduce students to the systems used to heat and sometimes cool different campus buildings, as well as to provide them with domestic hot water. Our aim is to expose the early college students to the installation of the power plant, without focusing on theoretical aspects, thermodynamic cycles, and properties of fluids, but focusing on understanding the functionality of different systems, as it comes from the drivers who take care of the power plant. This information accompanies the visits, where visualization is the main explanatory tool because these installations are generally noisy and it is very difficult to hear the explanation of the various maintenance personnel.

In this article, I will expand on my experience with mentoring STEM early college students to achieve a higher level of understanding of power plants. The aim is to contribute to the preparation of a STEM pipeline in the field of engineering and advanced manufacturing. The pipeline for research and higher education begins specifically at an early age, where students are encouraged to peruse STEM-related programs. Our program is mainly oriented toward high school, and early college students and continue through the completion of a college degree in STEM areas.

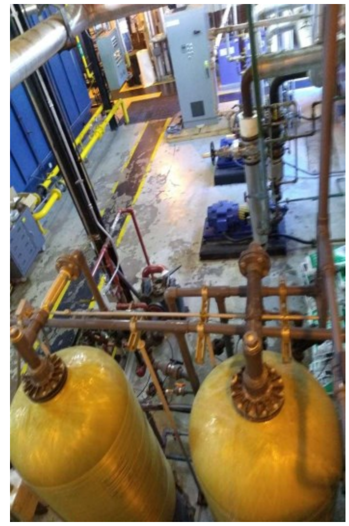
In this paper, we discuss the project design program from a student's perspective and experience gained in engineering, integration, written, and oral communication. The methodology used to improve the students' understanding of complex problems is also described.

Power Plant Installation at WAST:

NCAT State University's boiler system consists of many different, nested parts and machines. The power plant buys water from the city of Greensboro, the same water delivered to buildings, which is considered to be impure and cannot be used directly within a boiler without treatment. It goes through a set of processes to remove impurities. It penetrates a set of salt softeners that help remove heavy metals and other dissolved solids. It is then sent to a “DA (DeAerator) tank”, which removes dissolved oxygen, which can lead to erosion of the pipes.

Salt Softener

Inside Salt Softener

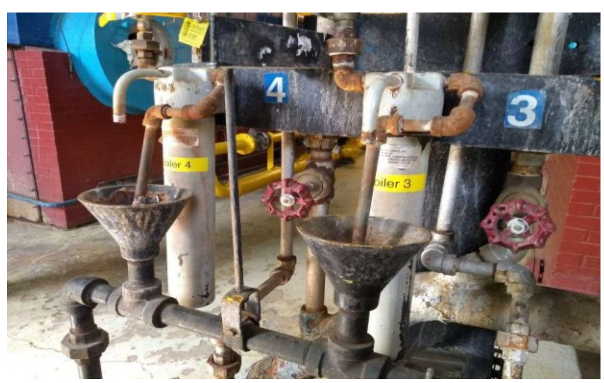


Second Part of Salt Softener

Figure 1: Softener from the NCAT Power Plant

A "feed pump" is then used to pump "the treated" water to the top of the "boiler". This water is pumped to the top, where it will be heated to higher temperatures and converted into superheated steam. The "sludge drum" is used to collect the impurities that are released during the evaporation process. The steam is moving using its own pressure and distribute to the campus buildings for heating and hot water applications, after undergoing a heat exchanger at the level of each building. To keep the water at desirable characteristics, certain chemicals are put into the water. However, these chemicals would be harmful to the pipes, so inside the boiler, when they float on top of the water, they are removed by surface skimming.

Chemicals and Measurements taken daily



Surface chemical Purge valves


Top of Boiler, where water is pumped in

Water Pump

Figure 2: Equipment and devices from NCAT Power Plant

The "boiler" produced steam, "mud" and exhaust gases. The exhaust is blown through large corrugated ducts. The mud collected in the "mud drum" has to be removed manually and will flow to the respective drainage system. Steam is extracted from the boiler and pumped to the campus for use.


Mud Drum


Exhaust Pump

Figure 3: Boiler Power Plant from NCAT

The boilers use three different fuels at different times. Typically, they use natural gas because it burns as cleanly and efficiently as possible. At times, like during parts of a harsh winter, they will use # 2 oil as it does not need preheating to be used. The oil is purchased when it is cheap and stored in two large tanks (without labor or special treatment). The third fuel is propane. It is only used for the ignition process and will be on for as long as needed to ignite other fuels. In order to ignite, the propane/air mix must contain from 2.2 to 9.6 percent propane vapor.

Fuel oil. No. 2 Diesel Fuel: A fuel that has a distillation temperature of 640 degrees Fahrenheit at the 90-percent recovery point and meets the specifications defined in ASTM Specification D 975. Oil prices seem more volatile and subject to demand and supply, natural gas comes with more stable supply and demand.

With boilers using combustion for heat, there must be a process to remove exhaust gases and emissions from the system. Above the boilers is a large corrugated duct, which helps distribute the heat from the exhaust. This duct usually leads to the chimney, labeled “Aggie land”. Steam is pumped to the campus distribution system (managed by the campus, not the power plant drivers). It is generally used to heat buildings and water. It can also be used to heat some of the larger cooking pans that produce large amounts of food. In each building, the heating of the water is provided by a "heat exchanger" where the steam from the boiler is drove around another stream of water, transferring the heat to the water, using mainly conduction and convection heat transfer mechanisms.

A heat exchanger is a device, where on either side of the tube, heat is transferred by convection. Heat is transferred through the wall of the tube by conduction. The two fluids (steam and water) of different temperatures circulate in spaces separated by a tubular wall with high conductivity. They transfer heat by convection and conduction through the wall.

Once the water is used up and the heat has been removed, it will find its way back to the boiler room, being pumped using gravity. This water, called "condensate", is placed in a condensate tank. It does not have to go through the purification process because it has already lost its impurities. However, it will have to go through the deaerator tank again, as the campus pipes are not perfect and have a big leakage problem, so the water will come out of the system, but the air will also enter, supplying oxygen to the system. It will go through the boiling process again, as it joins the system again, with new water, after the “DA tank”. It then goes through the entire process again.

In the event of a power failure, the plant has a backup generator so they can still provide heat to the campus. They use diesel to run this generator, which will only work in the event of a power failure.

Figure 4: Emergency Generator

Figure 5 is a visual flowchart that shows the process of steam generation. It supplies the series of systems in which the city water is taken and provides superheated steam to the campus. This steam is used to heat/cool the campus, such as air conditioning or domestic hot water. Steam also is used in cooking as some of the large industrial pots use steam to heat them as they require a large amount of constant heat. The steam from the plant is kept in a closed loop so that no water voluntarily leaves the system. The campus, therefore, has many "heat exchangers" that take thermal energy from the steam and transfer it to the sanitary water.

Much of the research in this area is material science. Researchers are looking for materials that will last the longest while best achieving their purpose. One of these elements is the header, which must be able to withstand immense changes in temperature (from the moment the boiler is turned on and off), without breaking or cracking. Researchers will test different materials for their longevity in each room. The book "Steam Power Engineering: Thermal and Hydraulic Design Principles" (Ishigai, 1999) explains more research topics like the materials used in other sections of the boiler and even the fuel used.

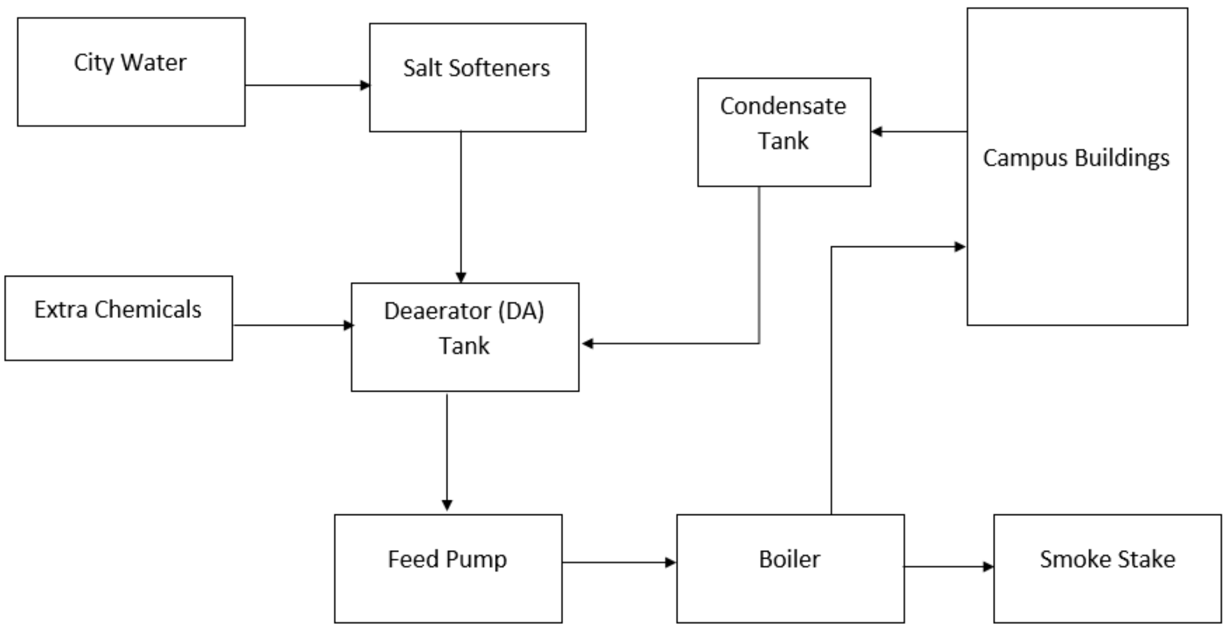


Figure 5: The flow of steam and condensate between the power plant and the campus buildings

Fuel can have a big impact on performance. The plant mainly uses natural gas as it is one of the cleanest fossil fuels. In winter, city gas pipes may undergo maintenance work or be out of order for a period of time. To accommodate this, the factory has two large blue oil drums containing No. 2 oil. However, the oil must be preheated before it can be burnt. A normal power plant usually uses coal, but it is possible to include biomass in a coal plant to reduce emissions. The research explains the process that could be used to implement biomass into the factory and the effects on emissions and energy production (Kraftwerk Forschung, 2015).

Each material does not need to be physically tested, as it could be expensive and time-consuming to perform the test on each material. Researchers can use dynamic simulation software called ANSYS. It works through the combination of modeling software and a dynamic fluid simulator. In the software, we are able to build the part under test, set its properties to those of the material, and then simulate an event, such as thermal or structural analysis. In the simulation, we are able to see the temperature and stress on individual areas of the part, seeing where a part can break or denature. This process could be used throughout the power plant system, testing the capabilities of each material for each part and finding the most optimal configurations for energy efficiency. Using the descriptions of the whole system from Minnesota State University (2018), we can decide which parts to study and how they are used.

Teaching Thermodynamics and Heat Transfer to minority:

Our work proposes to use a visit to a power plant for early college students to develop an empirical benchmark for the beginning of learning thermodynamics. We looked for what descriptions could be constructed by the students during such a visit and what links could be identified with the theoretical knowledge provided by the programs (Martinand, 1995). The work includes a part of analyzing the operation of the power plant in order to build modeling designs accessible to students. This analysis was made on the basis of the speech produced by a technician in charge of maintenance and the technical information made available to students by the professor. In parallel with the analysis of these data, ANSYS simulations were carried out with the students: visit then simulation work.

The work consists of analyzing every aspect of the power plant they observed. They provide information on what they spot, the questions they ask themselves, the ones they are making progress on, the links they try to establish with their theoretical knowledge. The articulation of these two components makes it possible to develop activities that can be offered to students, under the supervision of the faculty, in addition to experimental activities or formal exercises, so as to contribute to a better appropriation of the basics. Thermodynamics and heat transfer traditionally considered too formal. It is a work centered on various aspects: objects and phenomena observed.

The theory/applications link, essential for the understanding of any discipline, is much less simple and intuitive in thermodynamics than it is in other fields of physics. In the classic approach to teaching experimental sciences, such as example in electricity or mechanics, theory and applications to simple realizations are presented to the students at about the same time, with if possible some practical work.

At NCAT, the percentage of students who fail or drop out of fundamental courses, such as thermodynamics, is relatively high and this work is done to improve understanding of fundamentals through tours, labs, and simulation programs (figure 6). To recover from such a situation, multiple approaches have been developed, and consist of several aspects: (1) psychological help and encouragement of the students, (2) teaching them to use attractive methods to help the students to grasp complex subjects, (3) focus on visualization and hands-on teaching approaches.

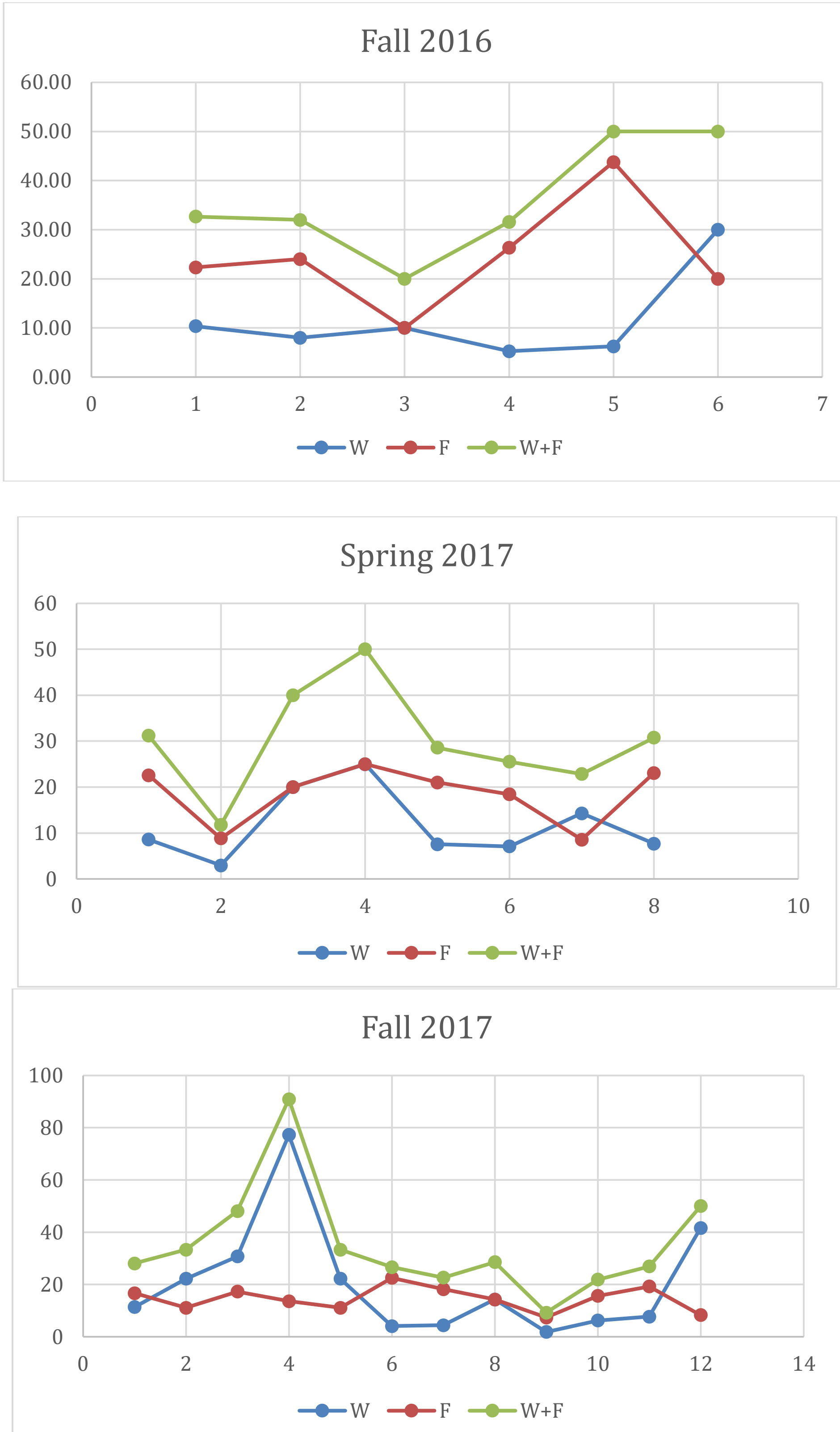


Figure 6: Freshman Fail and Withdraw percentage in 2016 and 2017 at NCAT

Work performed:

After the visits and discussions, the literature review, and the training, the students underwent simulation work using the ANSYS simulation program, where each student performs specific work related to either CFD, structural or thermal. After geometric modeling of a system, a mesh analysis is performed, followed by the setting up of physics, simulation, and analysis. The case studies are taken from real projects, such as thermal and structural analysis of a steady-state manifold. The analysis is guided by a graduate student, who works in the same field. Last semester, and due to the corona pandemic, this orientation was carried out virtually.

Evaluation and Methodology:

The success of the work was demonstrated through different outcomes, such as students who participated in the program were accepted by high-ranked universities in the mechanical engineering program. Other than that, the participation of the students to at least two different poster competitions (Appalachian Energy summit (2017 & 2018), and MSIPP Consortium for Advanced Manufacturing 1st, 2nd, and 3rd Annual CAM Scholar Poster Competitors), using the work learned under this umbrella, knowing that these competitions are usually designed for undergraduate and graduate university students.

More evaluation research utilizes mixed-methods approach employing both qualitative and quantitative data sources to determine the impact of the workshop on student learning. Consistent data from qualitative and quantitative methods increase the reliability of results.

Using the indirect course evaluation form, students were asked, anonymously, to self-assess their ability in specific areas identified by the instructor in connection with the course learning objectives, as well as the motivations for the program experience. The compilation of the results of the student-self-evaluation, as well as instructors' evaluation of course learning objectives questions, are presented in figures 7 and 8.

Conclusions:

Working with high school and early college students is a rewarding experience. Few of the college students I taught in the summer outreach program contacted me to follow them up on a project related to an application related to thermodynamics and heat transfer. My selection immediately went to the power plant, as it was full of lessons and engineering applications. Above all, every university has a power plant and workers who are full of experience and ready to share their experience with students with enthusiasm and dedication. The power plant is a demonstration laboratory that can be used to teach many engineering programs including heat transfer, thermodynamics, machinery, water treatment and water quality, materials, structure, combustion, and, more importantly, all these are undergone under dynamic conditions. Managing this mentorship was difficult, due to the time constraints and the corona pandemic. One of the advantages is the proximity of the early college to the engineering building. Research, education, and outreach are involved in this mentoring at several levels.

A learning approach was developed based on visualization and a computer program. Multiple visits and discussions with the power plant operators took place throughout the fall semester. Students did prepare reports and discuss issues raised by the faculty. Subsequently, training in the ANSYS software was carried out and the students conducted modeling and simulation work on specific subjects related to power plants. After all, they learn to give a clear and professional presentation and to defend their ideas and their work. Our goal is to help improve student performance to match leading technology in the United States.

The workshop included several interactive activities related to heat transfer, materials science, and thermodynamics, mathematics, and science. Using the current DOE fund, we plan to enhance this program over the next few years and come up with a model that will be used by other universities and institutions to improve STEM education and encourage high school and early-stage students. to pursue engineering training.

References

1) M. E. Loverude, C. H. Kautz, and P. R. L. Heron, “Student understanding of the first law of thermodynamics: Relating work to the adiabatic compression of an ideal gas,” Am. J. Phys. 70, 137-148 (2002); M. J. Cochran and P. R. L. Heron, “Development and assessment of research-based tutorials on heat engines and the second law of thermodynamics,” Am. J. Phys. 74, 734-741 (2006).

2) R. R. Hake, “Interactive engagement versus traditional methods: A six-thousand-student survey of mechanics’ test data for introductory physics courses,” Am. J. Phys. 66, 64-74 (1998).

3) N. Mulopa, K. M. Yusof, Z. Tasirc, “A Review on Enhancing the Teaching and Learning of Thermodynamics”, Procedia - Social and Behavioral Sciences 56 (2012) 703 – 712

4) Ishigai, S. (1999). *Steam Power Engineering: Thermal and Hydraulic Design Principles.*Cambridge, United Kingdom: Cambridge University Press.

5) Kraftwerk Forschung. (March, 2015). *Biomass in coal-fired power situations can reduce carbon emissions.* Retrieved from https://kraftwerkforschung.info/en/biomass-in-coal-fired-power-stations-can-reduce-carbon-emissions/.

6) Minnesota State University. (February, 2018). *Steam Turbine Power Plant*. Retrieved from https://cset.mnsu.edu/engagethermo/systems_stpp.html.

7) Interview of the Power Plant station’s employees & Students reports

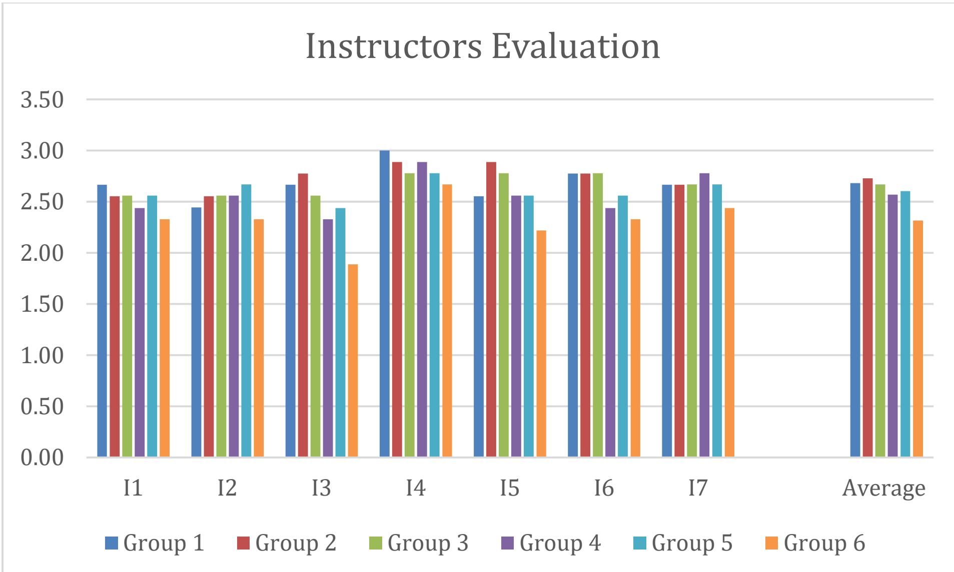


Figure 7: Instructors evaluation of course outcomes (0 is the worse and 3 is the best), according to ABET criteria 3 (each group is represented by a specific student).

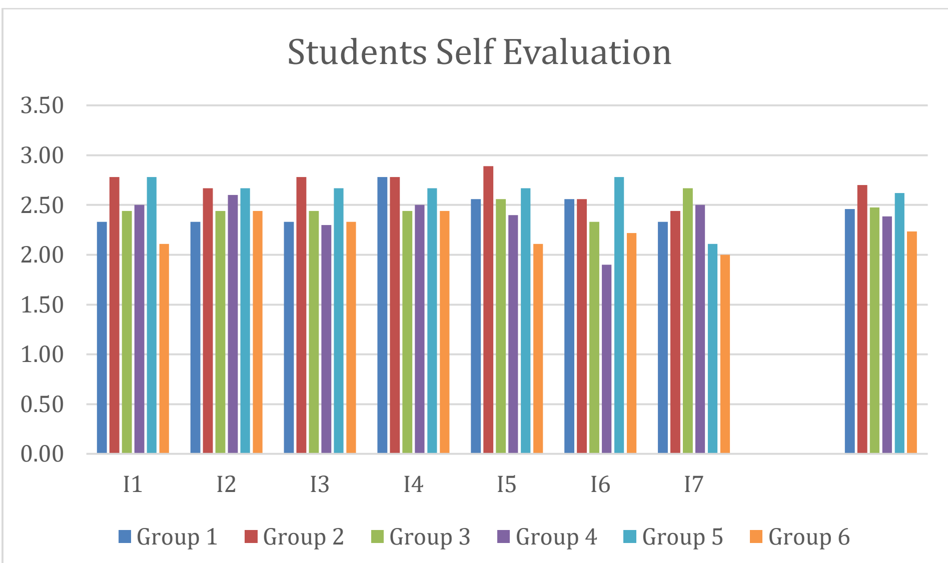


Figure 8: Students' self-evaluation of the course outcomes (0 is the worse and 3 is the best), according to ABET criteria 3 (each group is represented by a specific student).

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