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Preparing community college and high school students for inertial confinement fusion jobs in engineering and technology

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Abstract

The University of Rochester Laser Energetic Lab demonstrated the control of plasma instability in the condition of inertial confinement fusion in April 2023 and secured a 500 million dollars cooperative agreement with the US Department of Energy's National Nuclear Security Administration by December 2023, with new emphasis training for technicians, engineers, operators, etc. As an open-admission community college with Diversity Equity Inclusiveness (DEI) focus in an urban setting in New York State, a fusion-learning pedagogy was initiated to recruit and prepare students interested in fusion energy jobs, including those Science Technology Engineering and Math (STEM) students enrolled in the New York State Collegiate Science and Technology Entry Program. The pedagogy consists of experimental experience in laser alignment and Michelson interferometer techniques at Physics II Electricity & Magnetism level. Subsequently DOE awarded 100 million dollars to Rochester in the 2024 budget, for the implementation of broadband laser driven fusion with workforce development. The updated pedagogy consists of project experience in target alignment precision and Artificial Intelligence (AI) driven simulation, consistent with the products of the partner companies in the Rochester Fusion Consortium. The AI driven plasma simulation component was found to be better received by the students, in comparison to the target alignment component using the standard Kalman filter algorithm in Control Theory. The modification of the implementation to the high school students in Outreach program is presented, together with suggestions for improving the first assessment. Recruitment for out-of-state high school students via the New York State Excelsior scholarship pathway and the articulation agreement strategies to facilitate community college students interested in laser driven fusion jobs are discussed.

Introduction

Nuclear fusion driven energy sources are one of the primary objectives of the US Government Department of Energy. Three nuclear fusion development hubs were selected as of December 2023, namely, Colorado State University, Lawrence Livermore National Laboratory, and the University of Rochester [1]. About half of a trillion dollars has been allocated to the Rochester Fusion Consortium. The University of Rochester Laser Energetic Lab demonstrated the control of plasma instability in the condition of inertial confinement fusion in April 2023 and secured a 500 million dollars cooperative agreement with the US Department of Energy's National Nuclear Security Administration by December 2023, with new emphasis training for technicians, engineers, operators, etc. Local facilities, such as Monroe Community College, participates in the research, development, and education activities [2]. Subsequently, Department of Energy DOE awarded 100 million dollars to Rochester in the 2024 budget, for the implementation of broadband laser driven fusion with workforce development [3].

Learning objectives

We as faculty members in Queensborough Community College, a Diversity Equity Inclusiveness DEI community college in an urban area of New York, have decided to prepare our students who are interested to compete for the opportunities offered by the Rochester Fusion Consortium on inertial confinement fusion technology. The College's webpage says that "Our students hail from 127 unique countries and speak 78 different languages. We are a Minority-Serving Institution" [4]. The Science Technology Engineering and Math (STEM) students in the New York State Collegiate Science and Technology Entry Program (NYS CSTEP) program are also recruited as well.

The learning objectives include the (1) alignment of laser cavity and Michelson interferometer fringe measurement, in Physics II Electricity and Magnetism (E&M) Course, (2) target alignment in student projects using the standard Kalman filter algorithm in Control Theory and (3) Artificial Intelligence (AI) simulation in student projects in terms of fluid and plasma stability. The above experience could enable our students to compete for the Rochester LLE Undergraduate Internships which are recruiting nationwide [5], given the budget constraint in our Community College.

Pedagogy

The lab learning exercises of alignment of laser cavity and Michelson interferometer fringe measurement were routine in our former Laser Technology Program course. After the closing of the Laser Technology Program due to low environment, the lab deployment of the laser alignment and Michelson interferometer exercises in Physics II Electricity and Magnetism (E&M) Course have been straight-forward from the setup perspectives, although the students would need more experience to perform well when compared to the former Laser Technology Program students. We believe that a repeated training for a student would improve the alignment skills, just like those enrolled in the Laser Technology Program.

The alignment of lasers onto a fusion target has more constraints that can be solved by using the Kalman filter technique [6]. A most simple diagram illustration of the target alignment geometry with 6 laser beams can be found in an article on broadband laser plasma excitation [7], together with another introductory article of IEEE [8]. These articles were used to illustrate the professional standards and demonstrate the expected future math courses requirement. The student projects were implemented at an introductory level. The introduction of Kalman filter technique started with the 2001 ASEE article titled "Teaching Kalman Filters To Undergraduate Students" [9], and then followed by the 2012 IEEE tutorial article on Kalman filter [10].

The AI driven plasma simulation project implementation was based on the software products of Ergodic, a software simulation company partner of the Rochester Fusion Consortium [11]. The data fitting to extract plasma parameters such electron density and temperature from the Thomson scattering spectra via Python codes has been published by Ergodic on Github for easy access. The Yale Astrophysics 330 course taught by Pasha and Geha [12], with content posted on Github containing Python codes for spectra analysis were found to be useful as the first introduction for those students having taken an astronomy course already [13]. Pasha also published a free eBook on Python application starting with the UNIX System [14].

On the one hand, the Thomson scattering content was delivered using the Phenomenon-based pedagogy because the scattering of light by electrons is modeled with calculus skill beyond the level of a community college. On the other hand, light emission from an accelerating electron is within the technical calculus skill of a community college student. The inverse-distance dependence for the transverse electric vector amplitude in the radiation of an acceleration of electron was delivered in the Purcell's model using trigonometry and algebra [15]. Although an investigation reported that a phenomenon-based pedagogy can match a model-based pedagogy, we believe that some mode-based pedagogy is necessary especially for continuation to higher level courses [16]. The teaching of refraction using Snell's law with apparent depth calculation was classified as Phenomenon-based pedagogy. The teaching of wave model for refraction was classified as Model-based pedagogy. Data showed that some of all previously enrolled students, about 5 percent, returned to ask us about radiation questions when taking Electromagnetic Waves Fields classes at senior colleges.

The pedagogy can be illustrated with the following diagram, Figure 1

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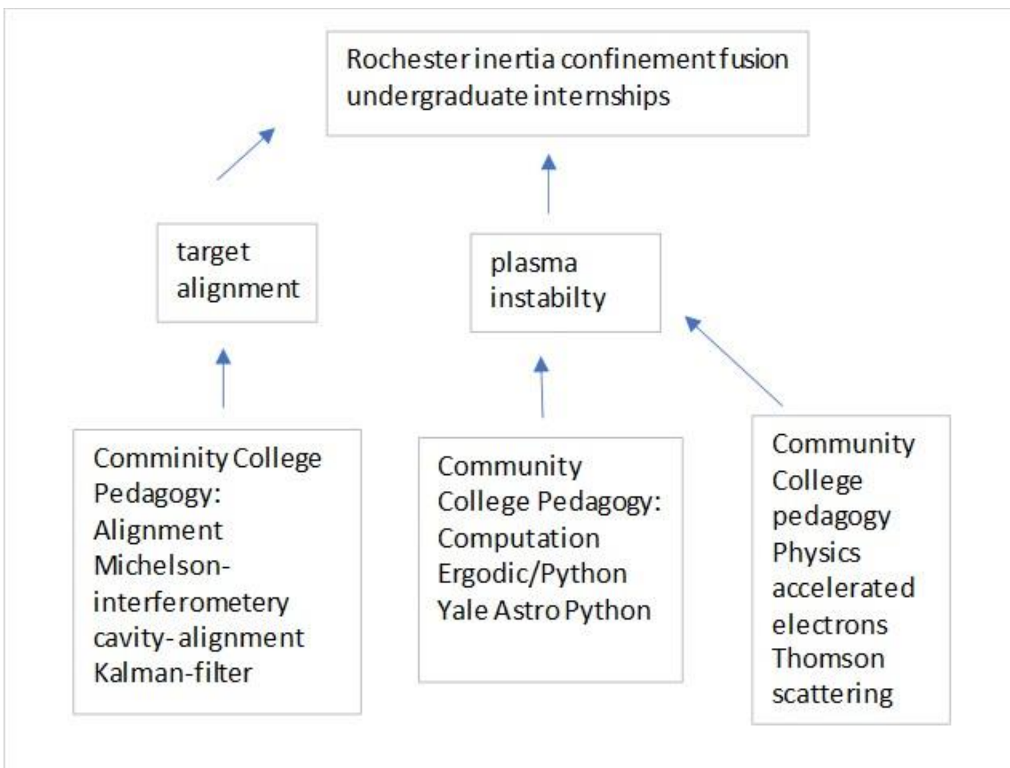

Figure 1: A diagram showing the pedagogies to help students to apply for the undergraduate internships in the Rochester inertia confinement fusion project.

Assessment

The learning deliverables in Physics II on the laser cavity alignment, Michelson interferometer, and Purcell's model of radiation of an accelerating electron were based on the what-if calculations of the related formulas. The assessment results were 50% "satisfactory" and 50% "needing improvement" using Equity perspective, N = 18. The equity perspective focuses on the delivery of a unique support for each student such that the learning outcome is uniform across the student population.

Out of the "satisfactory" status students, 3 of them expressed various types of aspirations toward the Rochester Fusion Consortium Program Internship Program. The continuation to the skill-learning projects generated mixed assessment results. The AI driven plasma simulation component was found to be better received by the students, in comparison to the target alignment component using the standard Kalman filter algorithm in Control Theory. The "effectiveness" was the learning of using Python codes (N = 0) and the "failure" was that they lost interests in the Rochester Fusion Consortium Internship Program (N = 3).

The materials posted by Matthew Schwartz of Harvard was selected as an example of model-based pedagogy [15]. Schwartz's webpage also contained real world applications in the physics of color, music and communication for interested students to broaden their horizon. That may be one of the reasons that none of the recruited students had continued to apply for the Rochester Fusion Consortium Internship Program after learning the instability investigation and Python computational skills.

Discussion of recruitment

When students are interested in doing undergraduate research projects with stipends under our Queensborough Community College Scholarship Program, we are not certain about whether the Rochester Fusion Consortium Internship Program commitment would remain as a high priority near the end of the instability and AI simulation projects. Therefore, recruitment starting at the Physics II course without the stipend information could serve as a filter for faculty to decide whether to teach the technical skills related to the inertial fusion confinement career when mentoring the student projects.

We found that a discussion of jobs is good for students during recitation sessions in which they were free to move around inside the lab space, when compared to the seating arrangement restriction in a lecture room setting. The Feb 2024 award of 1.5 billion dollars to GlobalFoundries (Headquarters: Malta New York) for chip production to support General Motors, etc. could attract more students to careers in semiconductor technology when compared to careers in fusion energy technology [17]. This report proposed a pedagogy to help those students interested in fusion energy careers.

Recruitment for out-of-state high school students via the New York State Excelsior scholarship pathway are on-going, an effort that follows our success of recruiting summer internship community college students over the country in our Queensborough Community College-NSF-

REU grants. There are two perspectives. Perspective-1: Since the computational projects can be delivered online, articulation agreement strategies to facilitate community college students interested in laser driven fusion jobs will receive College Upper Administration support with the first success of a future student being selected into the Rochester Fusion Consortium Internship Program. Perspetive-2: Our computational projects are using materials from open resources and currently available to all community college faculty members who have decided to improve their students' skills for the Rochester Fusion Consortium Internship Program competition.

Discussion of technical pedagogy

A toy model of Thomson scattering of plasma using our frequency doubled Nd:YAG laser was done as a student project. Although our Nd:YAG laser has about 0.01 Joule per pulse, unlike the 0.1 Joule per pulse used in the plasma diagnosis industry [18], the learning of plasma instability in a lab setting in terms of Phenomenon-based pedagogy for authentic experience is invaluable in our opinion. In comparison, the mayonnaise fluid model of Rayleigh-Taylor instability to mimic the plasma instability in the inertial confinement fusion cost 5 million dollars at Leigh University Mechanical Engineering Department would a better equipment [19].

The modification of the implementation to the high school students in Outreach program is planned for those interested in engineering physics and taking a research class (PH450 in our College). It is important to reduce the laser power so the requirement on laser safety lab setup will be satisfied when the high school students are working on the Nd:YAG pulsed lasers. A temporary transfer of the digital cameras with single photon detection sensitivity in our Robotic Telescope will reduce the Nd:YAG laser power requirement on the Thomson scattering lab for authentic experience.

As the 500 million dollars awarded to the Rochester Fusion Consortium must be utilized in the next 5 years, the above pedagogy methods for community college students are sustainable at low cost using the laser alignment and Michelson interferometer labs, with the free Python codes from Ergodic Company. The replacement of the Nd:YAG pulsed laser equipment with Nitrogen-dye lasers and advances in camera technology will lower the operating cost for faculty members with laser experience.

Conclusions

We have concluded that the Rochester Fusion Consortium Internship Program can be used to sustain interests in STEM students to learn the related skills. The instability investigation and Python computation skills are universal such that students switching away from the inertial confinement fusion career path after learning the skills can still use them in their future careers.

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