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UNDERGRADUATE HYPERSONICS RESEARCH: LESSONS FROM TWO YEARS OF THE REU SITE HYPER

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ABSTRACT
The University of Central Florida (UCF) trains future engineers and scientists for research-oriented careers through a number of programs and initiatives. One of the most recent is a Research Experiences for Undergraduates (REU) site based on next-generation transportation and energy housed within the Center for Advanced Turbomachinery and Energy Research (CATER) and the Department of Mechanical and Aerospace Engineering (MAE). The site unites eleven multi-disciplinary research projects around HYpersonic, Propulsive, Energetic, and Reusable Platforms (HYPER). A key goal of HYPER is to equip and motivate undergraduate students to pursue graduate school and/or a research-oriented career, particularly across a diverse student participant cohort. The site has held two cohorts, engaging 25 students in a ten-week intensive experience, conducting research under the guidance of faculty mentors and graduate students. Students explored career options through industry tours, professional development seminars, and mentor-led research seminars. This paper reports the program impacts on the students and discusses several lessons learned across the cohorts.

INTRODUCTION AND BACKGROUND
Training future engineers and scientists for the research-oriented careers necessary to deliver solutions to the challenges of hypersonic flight is an important task for the aviation, space, and defense communities. The REU Site HYPER cultivates and unites multidisciplinary interests to study advanced structures and systems with application to hypersonics, space, propulsion, and energy. Hosted by UCF within CATER, the NSF- and DoD-funded REU Site partners participants with faculty mentors and graduate assistants to provide hands-on training through research in PhD-level topics.

A key objective of HYPER is to prepare and equip students for research-oriented careers: participants tackle interdisciplinary contemporary challenges such as advanced manufacturing techniques for high-value components, ceramic matrix composite construction and non-invasive inspection of high-temperature parts, combustion studies of renewable fuels, and novel methods for improved internal cooling and heat transfer effectiveness. In all, eleven research projects are crafted to engage students in PhD-level topics. Many of these challenges rely on approaches that cut across disciplines and research techniques (e.g., experiments and simulations); Figure 1 depicts the general areas of focus.

Beyond the research, HYPER participants engage in a professional development series, industry tours, and computational software training. In addition, HYPER participants interact with the many other undergraduate students conducting summer research at UCF, both through other NSF REUs and UCF-initiated programs. This critical mass of activity enables successful workshops on graduate school preparation and research ethics, as well as social activities.

HYPER has six core objectives: (1) technically prepare students for graduate school and/or research-oriented careers; (2) escalate students' abilities to simulate phenomena using multi-

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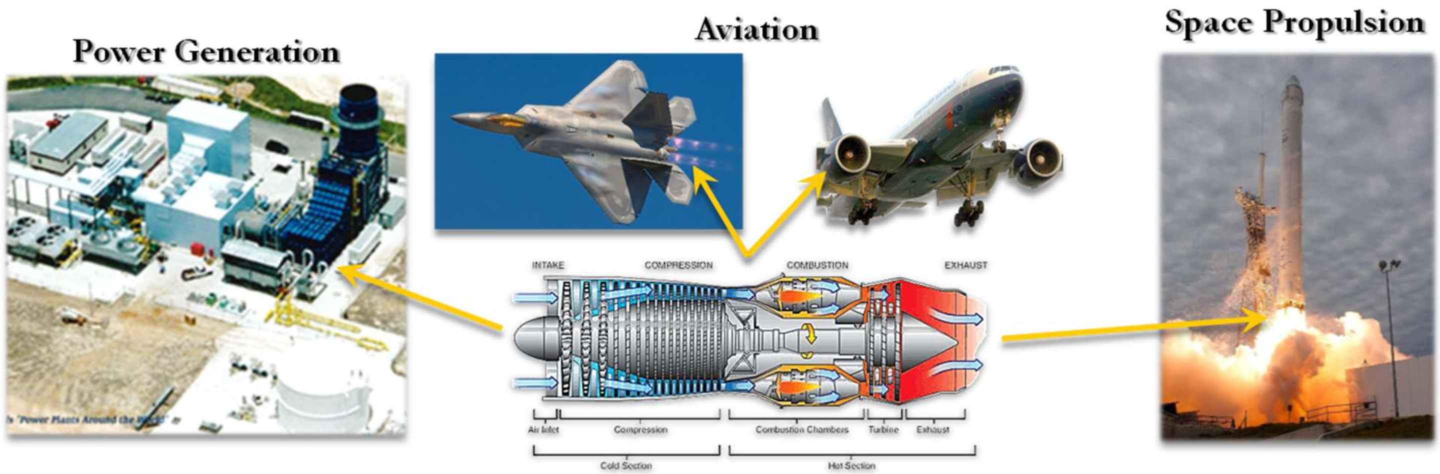

FIGURE 1. HYPER ADDRESSES MULTIDISCIPLINARY RESEARCH RELATED TO HYPERSONICS, SPACE, PROPULSION, AND ENERGY. MANY OF THE RESEARCH PROJECTS INVOLVE ADVANCED TURBOMACHINERY TECHNOLOGY

physics based finite element analysis; (3) improve participants' communication skills through repeated oral and written technical research reporting; (4) enhance participants' research skills and attitudes about contemporary and futuristic technologies for power generation, hypersonic flight and space propulsion; (5) present an REU site that is diverse in terms of student participation (e.g., prior research experience, age) and (6) provide high-quality mentoring to prepare the students in the program for research-related careers. Included in this research program is an independent annual assessment of the Site through pre- and post-experience surveys, study groups, and other assessment activities.

This REU site seeks to meet the six objectives above by focusing the participant experience on next-generation transportation and energy. These decisions were inspired by the recent advances in potential transportation modes, increased propulsion efficiency, and the associated decreased travel cost [1,2]. Recent research has identified the need for advanced platforms for transportation and electric power generation to support these business cases for [3,4]. These technologies still exhibit significant performance gaps that limit their application; this projects seeks to produce the researchers who will create the transformative technologies that will bring about new transportation and energy systems [5,6,7]. Reusability and efficiency of propulsion systems in current-generation platforms have steadily improved, but transformative advances to turbomachinery and propulsion systems, materials, and manufacturing is vital to reduce both the costs and emissions associated with manufacture and operation [8]. Early results from the 2019 cohort indicate HYPER is accelerating progress and igniting excitement in the current generation of students to pursue research-oriented careers tackling these multidisciplinary research challenges [9,10].

COVID-19 Impact

The first year of HYPER occurred in summer 2019. The response to COVID-19 prevented UCF from hosting HYPER in 2020. In 2021, UCF hosted a modified version of the program; this paper presents results from both Year One (2019) and Year Two (2021) cohorts. HYPER currently is recruiting for a Year Three cohort to take place in summer 2022.

HYPER PROGRAM ELEMENTS

Research Project Objectives and Accomplishments

The HYPER program runs for ten weeks from late May through July. Each year's cohort nominally consists of eleven students; each conducted research directly with a faculty mentor and a graduate student. However, in 2021, HYPER was able to partner three additional students with research mentors through externally funded programs. These fourteen participants engaged in the following eleven hypersonics-related research projects as described at the time of application on the main site [`http://cater.cecs.ucf.edu/hyper`]:

Continuum-Level Life Prediction of Materials under Combined Extreme Environments, with a goal to conduct a numerical analysis of thermo-mechanical buckling in combined extreme environments. The project has applications for the stability of fuselage panels in hypersonic vehicles. The participant will learn to conduct finite element analyses (FEA) using ANSYS and simulate the transient response of a long flat plate subjected to high temperatures to assess its stability. The participant will incorporate advanced nonlinear material and constitutive properties/models into the FEA.

Damping of Anisotropic Composite Structures Under Extreme Multi-Axial Mechanical and Thermal Loads, with a goal to establish a testing framework to understand how multi-axial mechanical loads affect the damping of anisotropic composite structures. The project has applications related to the structural dynamics of hypersonic vehicles. The participant will develop and build a test rig that imposes controllable multi-axial loads and can accommodate mixed boundary conditions, characterize the rig using an initial test specimen, and gather experimental data on the trends of damping based on in-plane loading. The participant will also simulate the effect of boundary conditions to optimize the specimen plate geometry and support mechanisms.

Evaluation of CFD Models for Solid-Propellant Rocket-Exhaust Modeling, with a goal to explore numerical methods relating to solid-laden flows for rocket propulsors. The project has applications relating to rockets, sand blast nozzles, coal processing, and other applications involving flowing particulate. The participant will learn to master research tools such as computational fluid dynamics, multiphase flow, and key concepts of compressible jets. Using these research skills, the participant will evaluate a variety of numerical methods; the work directly points to an improved path for nozzle optimization.

Atmospheric Entry, Descent and Landing (EDL) for Manned Mars Missions, with a goal to develop a new method using neural networks for a Mars capsule controller during atmospheric entry. This method utilizes the controller from the Apollo missions as a reference for data when training the neural network. The participant will contribute to on-going research by conducting the simulation with the trained network to replicate the results from Apollo with variations in the initial conditions, e.g. position. The participant will then use the real data from Apollo to evaluate the controller's performance. The controller will then be adapted to the Mars environment where it will satisfy the requirement for landing accuracy.

Non-Invasive Inspection of High-Temperature Coatings, with a goal to develop material systems that can endure the extreme conditions associated with hypersonic flight. The project has applications of material design for hypersonic and extreme environments. The participant will contribute to on-going research by conducting a literature review on possible substrate and coating materials for the candidate samples for testing. The participant will identify the typical X-ray emission peaks for these materials for ease of testing.

Transpiration Cooling for Turbine Blades as Enabled by Additive Manufacturing, with a goal to investigate the effects of applying mechanical loads to auxetic designs that could be used as film-coolant slots. The project has applications in gas turbines, where enhanced cooling could increase the maximum turbine temperature, thus increasing its energy efficiency. The participant will learn to conduct finite element analyses (FEA) using Siemens NX and simulated the behavior of auxetic slotted plates subjected to force and pressure loads. The participant will simulate both flat and cylindrical coupons, and the results indicate specific slot shapes that produce the least deformation and lowest stress concentrations.

Additive Manufacturing of Ceramic Turbine Blades, with a goal to design an experimental testbed for evaluating the performance of carbon fiber reinforced polymer composite gears. The carbon-fiber-reinforced polymer composite gears have a wide range of applications in lightweight aerospace components. The participant will design and 3D printed several carbon fiber reinforced polymer composite gears as well as design a health monitoring system for the testbed.

Fundamental Combustion Studies of Renewable Fuels for Hypersonic Propulsion and Rocket Engines, with a goal to develop a Matlab model for an advanced 3D tomographic optical diagnostic technique of flames. The model is used to investigate and measure heat release in premixed hypersonic compressible turbulent flames models for hypersonic propulsion. The student will develop a Matlab code and start the generic image processing.

Uncertainty Quantification and Massive Computing in Prognosis and Fleet Health Management, with a goal to improve the fidelity of inputs used in the physics-informed machine learning model for corrosion fatigue. The project has applications of Python coding and large data analysis. The participant will contribute by a) identifying available data regarding airport corrosivity indices such as salt, CO, and humidity levels across the USA (looking at databases from NOAA, NREL, and others); b) coding computational routines for data curation (dealing with outliers and missing data); and c) performing literature research and coding a model that maps such indices into a corrosivity severity factor. At the end of the summer, the participant will deliver a dataset with five-year of data for ten airports in the USA.

Flame Diagnostics Using an Advanced 3D Tomographic Optical Technique, with a goal to analyze flame speed measurements from constant-volume combustion chamber. The project has applications in design of engines used in hypersonic airbreathing vehicles. The participant will analyze images to obtain flame speeds from high-speed videos.

FIGURE 2. HYPER PARTICIPANTS ENGAGED IN PROFESSIONAL DEVELOPMENT AND SOCIAL ACTIVITIES LIKE (A) ANSYS TRAINING SEMINARS, (B) A NIGHT-TIME BIOLUMINESCENCE KAYAK TOUR, (C) TOURS AT NASA KENNEDY SPACE CENTER, (D) A ROPES COURSE, AND (E) ICE SKATING

3D-Woven Polymer-Derived All-Oxide Ceramic Matrix Composites (CMCs), with a goal to develop high temperature oxide-oxide ceramic matrix composites. The project has applications of hypersonic vehicles, gas turbine blades, and aircraft engines. The participant will process, characterize, and test the oxide-oxide CMCs.

Training, Professional Development, and Social Activities

HYPER participants spend the vast majority of their time conducting graduate-level research with their mentors and graduate student partners. The program supplements this immersive activity with professional development opportunities, industry site visits and tours, group research seminars, ANSYS training sessions, and social events to foster a stronger cohort, as seen in Figure 2. The extensive summer research activity at UCF also enables “cross-REU” events that join HYPER participants with those from other UCF-hosted REUs researching nanotechnology or the Internet of Things, among other topics. Of course, students also engage in more organic gatherings. One great advantage UCF has is the proximity to Cape Canaveral; many participants travel to the coast to observe rocket launches. (The Year One Cohort took a group trip to see the late-night Falcon Heavy launch in June 2019.) In fact, participants can even enjoy the launches from UCF’s main campus: it is only 35 miles west of the launch sites, so the rocket plume is typically observable from the time it is above the horizon through Main Engine Cut Off. For night launches, even the Stage 2 plume is generally visible to the naked eye.

COHORT RECRUITMENT

Recruitment Efforts

HYPER recruits broadly, utilizing a variety of methods to develop a suitable applicant pool. HYPER organizers typically use online media, the HYPER website, direct emails to engineering departments at US universities, distribution of a HYPER flyer to each project mentor’s technical community, and UCF MAE social media channels. Additional details on the recruitment efforts and the demographics of the resulting applicant pools and cohorts are published in [9, 10].

Year One to Year Two Recruitment Differences

In general, recruitment runs from December through March, and evaluation and selection of applicants occurs in late March and early April. This schedule allows adequate time for final participant notification, travel planning, and initial setup at UCF, which includes elements like housing reservations, key cards, network accounts, and so on. In 2019, however, recruitment occurred on a compressed timeline: following award notification in March 2019, evaluation and selection of final participants took place in mid-April. Starting from the full applicant pool, the HYPER directors first apply the preferred criteria, then select approximately 50 applicants for further review with individual faculty mentors. This process concludes with selections of the final cohort of participants (eleven and fourteen undergraduate students in Years One and Two, respectively).

Thus far, HYPER has recruited diverse applicant pools, attracting over 1,100 applications across the two years. Approximately half of the applicants met the HYPER preferred criteria, which includes GPA, major, research interests, etc. Notably, that percentage increased markedly from Year One to Year Two, from 20% to approximately 80%. As addressed above, the Year One recruitment occurred on a compressed timeline, so HYPER organizers advertised and recruited very broadly. The initial calls for applicants encouraged applications from students seeking a wider range of degrees for Year One. In retrospect, a more targeted pool could have been developed even with only one month of advertising. With this experience and the additional time for subsequent advertising and recruitment, a slightly smaller but stronger applicant pool was developed in Year Two.

HYPER's overall acceptance rate is approximately 2.3%. It was only 1.6% in Year One and increased to 3.3% in Year Two. However, the broad recruiting in Year One means that the Year Two process actually was more selective—we arrive at that conclusion by considering the applications that matched the preferred criteria. Approximately 8% of Year One preferred applications were selected as HYPER participants; in Year Two, only approximately 4% of preferred applications were selected.

Applicant Pool Post-Graduation Plans and Prior Research Experience

Based on the Year One hindsight regarding broad versus more targeted advertisement, the Year Two HYPER application included questions regarding prior research experience, post-graduate plans, and interest in pursuing graduate school. Considering first the immediate post-graduate plans, the majority of applicants planned to attend graduate or professional school (53%). Another 31% planned to seek employment in industry immediately upon graduation, though 65% of these students also indicated an interest in pursuing a graduate degree at some point in their careers. Approximately 10% were unsure of their post-graduation plans, 1% planned to pursue entrepreneurial activities, and the remaining 5% listed "Other" as their intended post-graduation activity. Most of these last 5% provided additional comments regarding their plans; 1.7% planned to join military service, 1.2% planned to seek employment and to pursue a graduate degree simultaneously, and 0.7% were deciding between seeking employment and pursuing a graduate degree. The final Year Two cohort largely matched this overall diversity of plans: 50% planned to pursue a graduate degree, 36% planned to seek employment, and 14% were unsure. (These plans were expressed pre-HYPER experience, during the application phase.)

Turning to prior research experience, only 37% of applicants indicated they previously had conducted research. Here, the cohort selection did not match the applicant pool, suggesting either that applicants with prior research experience are more likely to have stronger applications than those without research experience or that application evaluators exhibited a preference for research experience. (This question was not explicitly taken into account during evaluation; however, letters of recommendation and personal essays from the applicants typically reveal prior research experience and the impact it can have on an applicant's development and preparation.) Within the Year Two cohort, 57% of participants had prior research experience. This statistic shows that a significant number of HYPER participants have no research training coming into the research experience. In the longer term, HYPER organizers hope to observe whether any trends emerge among participants with prior research experience, for example, whether they are more likely to publish their findings in conferences and journals or how their self-reported research skills/attitudes might change pre- to post-experience.

Combining the post-graduation plans with prior research experience reveals additional information that can help to shape future cohort selection. Of the applicants indicating post-graduation plans of pursuing a graduate or professional degree, 46% indicated they had prior research experience. This statistic is well above that for all other post-graduation plan categories, which ranged from 25% to 29%. Among the selected participants who planned to pursue a graduate or professional degree upon graduation, 71% indicated they had prior research experience. As above, this statistic may simply reflect stronger applications or a preference of the evaluators. However, among the 2021 participants who planned to seek employment or were unsure of their post-graduation plans, only 43% indicated they had prior research experience.

The initial application also included a question on applicant's interest in pursuing a graduate degree at some point in their careers. (That is, some applicants might prefer to seek industry employment immediately upon graduation but remain interested in pursuing a graduate degree at some point in the longer term.) Approximately 70% of applicants expressed interest in a graduate degree; the cohort selection nearly matched this number exactly at 71%. Overall, the 2021 cohort of 14 participants was diverse in terms of post-graduation plans, prior research experience, and long-term interest in a graduate degree.

IMPACTS

The HYPER directors assess the program impact through both faculty-administered technical quizzes and feedback as well as independent evaluation through the Program Evaluation and Educational Research Group (PEER). This process incorporates questionnaires and a focus group at the pre-, mid-, and post-experience stages.

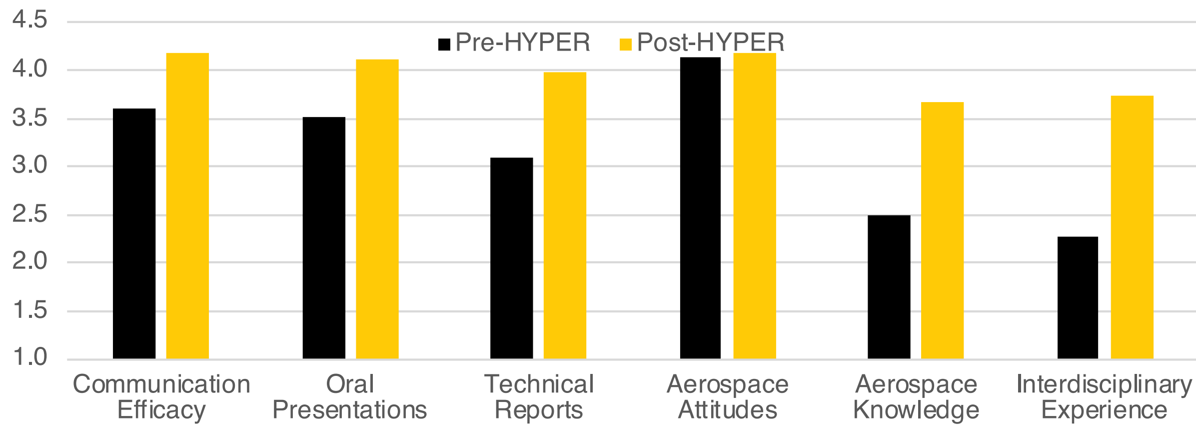

FIGURE 3. SELF-REPORTED SKILLS AND ATTITUDES IMPROVED OVER THE COURSE OF THE 2019 RESEARCH EXPERIENCE

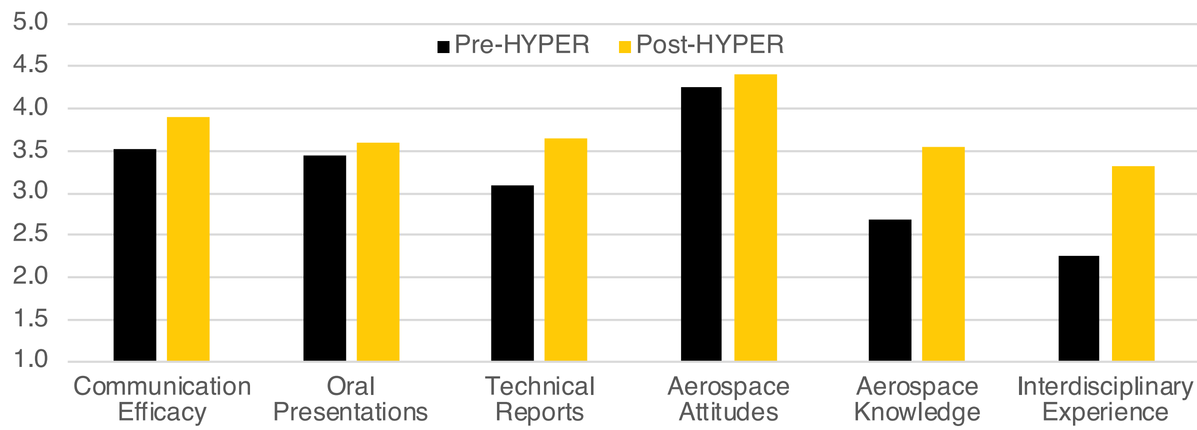

FIGURE 4. SELF-REPORTED SKILLS AND ATTITUDES IMPROVED OVER THE COURSE OF THE 2021 RESEARCH EXPERIENCE

Initial Evaluation Data: Year One Highlights

Evaluations of participants' technical knowledge showed marked improvement pre- to post-experience, with participant quiz scores jumping from 50% to 90%. Participants also recognized their newfound abilities, self-reporting significant gains in both research skills and attitudes about contemporary and futuristic technologies [11]. Relevant to the HYPER goal of equipping students for research-oriented careers, participants saw their self-reported research self-efficacy soar, from 3.3/5 pre-experience to 4.3/5 post-experience. Not surprisingly, participants overwhelmingly rated the industry tours among the highlights and most valuable programmatic aspects beyond the research.

COVID-19 Disruption: Year One and Year Two Differences

COVID-19 disrupted HYPER plans: there was no cohort for 2020, and Year Two (2021) took place with reduced face-to-face interaction. The industry site tours were removed entirely for 2021 and most professional development activities took place virtually over Zoom. Social activities continued in person for those who felt comfortable doing so; the 2021 program also included several opportunities for social interaction over Zoom.

A good first point of comparison is participants' self-reported skills and attitudes regarding research and advanced aerospace topics. Students responded to approximately 20 survey questions that are mapped to 6 categories: communication efficacy, comfort and ability delivering oral presentations, comfort and ability writing technical reports, aerospace attitudes, aerospace knowledge, and interdisciplinary experience and skills. Figures 3 and 4 display the pre- and post-experience scores.

In all categories, participants indicated an increase in skills/attitudes from pre- to post-experience. Perhaps the largest jump came in the area of interdisciplinary experience and skills, with participants' self-reported scores increasing from 2.3/5 to 3.5/5. The second largest increase came in the area of aerospace knowledge, from 2.6/5 to 3.6/5. The area with the smallest increase is in aerospace attitudes, which measures participants' interest and excitement in topics of advanced transportation and power generation relevant to hypersonics. Participants began the experience with high levels of excitement and interest, self-reporting their attitudes as 4.2/5. Nonetheless, the HYPER experience still increased those levels to self-reported scores to 4.3/5.

One very clear difference between the Year One and Two cohorts is the change in self-reported scores from pre- to post-experience. Of note, most pre-experience scores are remarkably similar across the cohorts. The largest change was in aerospace knowledge: the Year One cohort self-reported knowledge of 2.5/5 compared to the Year Two cohort mean score of 2.7/5. The other five categories showed at most a 0.1/5 shift in score from Year One to Year Two. However, the Year One cohort reported an average gain across the six categories of 0.8/5 compared to only 0.5/5 for the Year Two cohort. Thus, the Year Two cohort reported approximately two-thirds of the gains across these six categories as Year One participants reported. One potential reason is the limited opportunity for larger interactions that COVID-19 imposed. Indeed, the smallest gain in Year Two is in the area of comfort and ability delivering oral presentations. The response to COVID-19 limited larger group meetings in which participants often might deliver and practice their presentations. Additional presentation opportunities moved to a virtual format, which may make presenting easier but also does not give the participant the experience of presenting face to face; thus, participants may not gained less confidence in their ability since they presented under less stressful conditions.

The next largest drop off from Year One to Year Two was in the area of interdisciplinary experience and skills [11, 12]. Year One participants reported a pre- to post-experience jump from 2.3/5 to 3.7/5; for Year Two, it was 2.3/5 to 3.3/5—still a remarkable increase, but also markedly less than in Year One. Once more, the limited opportunities for interaction may explain this difference: with less direct exposure to other research projects, participants likely did not get as complete a picture of the relations between the projects. One final point: both cohorts heard weekly research seminars on the various topics and had a weekly "check-in" following the seminar. However, face-to-face check-ins are much more conducive to organic discussion of how a participant's research relates to others. The Year Two cohort did show a marginally larger gain in aerospace attitudes pre- to post-experience.

In the post-experience surveys, participants also rated the value and utility of the professional development seminars. The Year One cohort found these seminars very useful, rating them at an average level of 4.3/5. As such, an increased number of more diverse professional development seminars were offered for Year Two. The Year Two participants found these offerings valuable, but to a lesser degree (3.2/5) than in Year One. There are likely several factors in play, but COVID-19 again likely plays a significant role since these seminars were delivered via Zoom to ensure social distancing. The increased number of seminars might also play a role as participants could have been overwhelmed by the offerings. Finally, the seminars were presented for all undergraduate students conducting research at UCF in Summer 2021, so they covered more diverse topics and may have been less tailored to the HYPER cohort. However, even nominally identical seminars (e.g., Preparing a CV/Resume) were rated more valuable in Year One than in Year Two, indicating that other factors like virtual delivery or larger audience size may be key factors.

The Year Two cohort also lamented the lack of industry site visits/tours [12]. The Year One cohort rated these visits as the most impactful element of the program after the actual research, so it was frustrating to not be able to offer these opportunities [12]. Indeed, in an open-ended post-experience anonymous survey, participants routinely identified industry tours as a significant frustration. COVID-19 negatively impacted HYPER in other ways, too. In that same survey, participants indicated some frustration surrounding basic logistics like housing questions, access to recreation facilities, and key cards. Even with frequent virtual interactions, one can imagine participants may be reluctant to address these issues—in a face-to-face meeting, a participants can easily initiate a private conversation by pulling an organizer aside; in a Zoom room, doing so quickly identifies the student as having a potential issue. The uncertainty regarding COVID and the ongoing "Delta wave" also affected the social activities, with some details only worked out at the last minute to accommodate changing conditions. Participants noticed this uncertainty and identified it as a main frustration in the post-experience survey.

Finally, Fig. 5 shows participants' post-experience perceptions. Despite the disruptions and uncertainty due to COVID-19, all participants agreed or strongly agreed the experience was fun and connected the participant with other similarly oriented students. In addition, 79% of participants stated the experience was challenging and connected the participants with helpful faculty. More importantly, 79% of participants also indicated the experience helped them better understand how to do research and to decide whether to pursue the fields of mechanical, materials, aerospace, and/or energy engineering.

Looking Ahead to Future Cohorts

Our approaches to conducting the site despite COVID-19 point to future possibilities. Returning to the post-experience comments, one student who had hoped for more hands-on and in-person events commented that much of the experience could have been conducted remotely. Indeed, that may be a useful tool to enable greater participation. It seems the hybrid nature may have caused the greatest frustration, so offering both a fully in-person

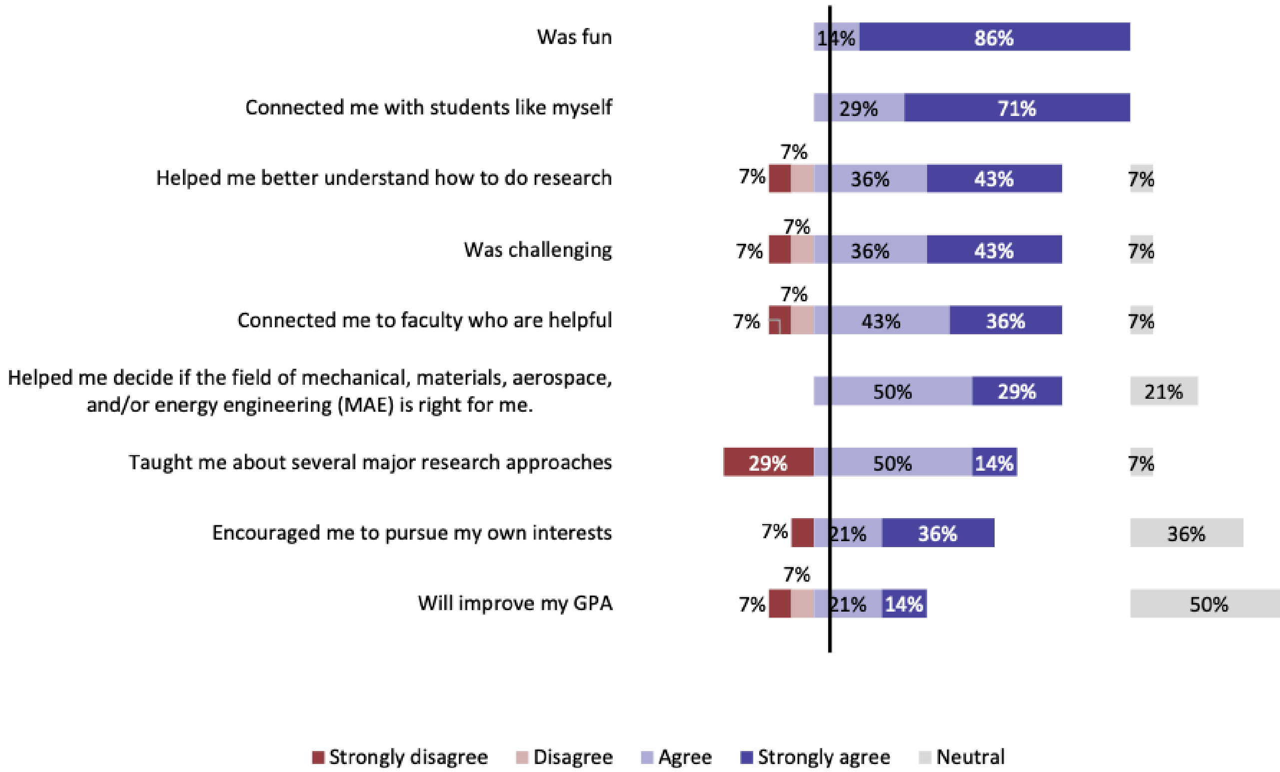

FIGURE 5. POST-EXPERIENCE PERCEPTIONS OF HYPER 2021. FROM [12].

experience and a fully virtual experience with program elements tailored to each modality may be a future path. We already identified several logistics items to address for 2022, from securing key cards earlier to providing more frequent cohort-wide communication. Should a hybrid modality be necessary again in 2022, we plan to structure additional opportunities for solo interaction to address individual questions as they arise.

CONCLUSIONS AND LESSONS LEARNED

The REU site HYPER addresses challenges in next-generation modes of transportation and energy generation. HYPER participants' research will play a part in developing high-speed terrestrial and space transportation modes and breaking the associated cost barriers. HYPER participants reported positive experiences, though COVID-19 certainly limited the benefits of the REU in 2021.

A comparison of Year One and Year Two cohorts show that while starting recruitment and advertising several months before application evaluation is preferred, a diverse and talented pool can be amassed even with only a month of recruitment and advertising. The limited interaction and opportunities due to COVID-19 negatively impacted the REU in several ways; if HYPER 2022 also must employ physical distancing and remote operation in some capacity, we look forward to creating additional opportunities for direct interaction among participants. Specifically, participants should have additional training and coaching on delivering oral presentations, as well as increased opportunities to present their research. Finally, participants should have additional exposure to cross-project presentations and discussions so they can better understand the interdisciplinary nature of the HYPER research.

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