Lessons learned from the NSF IGERT program: cultivating student motivation in the interdisciplinary and international context

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Abstract

The National Science Foundation (NSF) Integrative Graduate Education and Research Traineeship (IGERT) Program: Global Traineeship in Sustainable Electronics” brought together an interdisciplinary group of students to study the environmental, economic, and societal aspects of the global electronics lifecycle. There were three cohorts altogether, but the dynamics of each group were substantially different. This third cohort actively sought additional experiences outside the original planned courses and trips. The aim of this work is to glean insight into what and how specific curriculum design may promote the learning experiences in which students take initiative beyond the scope of the programs. We identified four factors that might influence the experiential learning within a framework incorporating the self-determination theory (SDT) and the expectancy-value model: value, relatedness, competence, and autonomy. Utilizing a non-experimental approach, we surveyed the last cohort to identify when and why they felt or failed to feel motivated during the program and what curriculum modules were most valuable for their learning experiences. We found that all four factors (value, relatedness, competence, and autonomy) grew throughout the program. In particular, the international workshop in India marks the point when students started to see shared values with their peers; the self-organized seminar course marks the point when students developed the feeling of autonomy. The most valuable aspects of the program were ranked to be international field trips, peers, and team projects. For the latter two aspects, defined in this work as the group dynamic, the most important factors for building a sense of community are group pro-activity, cohesiveness, and attitude.

Introduction

The emerging call for future engineers with global-citizen mindsets asks for a re-evaluation of current educational experiences provided in higher education. In the U.S., participation in study-abroad programs for students majoring in engineering has increased more than 50% over the past decade [1]. Study-abroad programs represent the general interest of exposing students to other cultures or environments so that they become competitive professionals in the globalized world [2], [3]. Specifically, this outcome was highlighted by the National Academy of Engineering, whose recently reported initiatives emphasize the importance of international learning experience [4]. Apart from international learning experiences, interdisciplinary curricular development in higher education has attracted many educators’ attention and was reported to be suitable for topics that require inputs from both STEM and non-STEM fields [5]–[7].

In light of this emphasis on expanding students’ education, the Interdisciplinary Graduate Education and Research Traineeship (IGERT) program was developed by the National Science Foundation as a traineeship that prepares graduate students to enter the workforce by focusing on collaborative, interdisciplinary training. A multi-year traineeship was established at Purdue and Tuskegee Universities and is focused on sustainable electronics. Graduate student trainees
conduct research in fields relevant to electronics and sustainability and take four classes in addition to participating in annual workshops, domestic industry trips and an international trip to India. Of the three cohorts sponsored by the program, the final IGERT cohort went beyond the original programming of the curricula. For instance, when their final class was canceled due to a professor’s sabbatical, the class proposed a student-led seminar class in which the curriculum was designed to fill in the student-reported knowledge gaps from the cohort. This research will focus on the experiences of the third, final cohort from the IGERT “Global Sustainability in Electronics Traineeship” which exhibited a high level of self-motivation throughout their tenure.

Considering the international and interdisciplinary setting for the IGERT program, it is natural to assume the self-driven activities were related to this setting. However, few studies with similar learning settings reported how student motivation changed [8], [9]. With limited literature on interdisciplinary or international programs that affect student motivation, the teaching practices that led the third IGERT cohort to be self-motivated are valuable to identify.

**Study Purpose**

With an increasing number of engineering curricula being designed with interdisciplinary or intercultural settings, the aim of this work is to evaluate the influence of specific course design and implementation on students’ motivation in teaching practices, within a structured framework of self-determination theory [10] and expectancy-value model [11]. With the "NSF IGERT: Global Traineeship in Sustainable Electronics" as a suitable example, this paper is guided by two questions: "What kind of motivation were exhibited and changed throughout the IGERT program?" and "If changed, what projects or educational experiences triggered it?"

**Theory and Background**

**Theoretical framework of motivation**

Motivation theory provides the groundwork for learning and teaching for students and educators. Svinicki [12] and Perkins [13] extensively discussed how to develop curricula that foster the motivations of students. Motivation is studied with respect to learners, contexts, and cultures [14, Ch. 6]. We will use self-determination theory (SDT) as the main framework for this study. SDT applies to the topics of motivation, arguing that there are three key elements contributing to intrinsic motivation: autonomy (i.e., feeling one’s behavior is self-determined and fosters intrinsic motivation), competence (social-contextual events - i.e. feedback and rewards - that contribute to feeling qualified or skilled), and relatedness (a sense of security and connection in interpersonal settings). The expectancy-value-cost model [11] is used as a secondary framework to examine value as a factor in student motivation. Because the "expectancy" factor resembles the "competence" in the self-determination theory and the "cost" is oftentimes categorized into the "value" factor, only the “value” factor is incorporated into our theoretical framework.

In conclusion, we identified the four factors in motivation theory, i.e., value, relatedness, competence, and autonomy, as the reference for guiding our research questions.
Student motivation in an interdisciplinary and intercultural learning environment

Relatively few studies are available where interdisciplinary and international elements were a part of the course design and student motivation was measured. However, publications can be found in either field (interdisciplinary or intercultural environment). For instance, McCormick et al. [15] examined a service-learning program at Tufts University which was deemed a valuable complementary resource to the conceptual knowledge taught in college-level courses. They observed that the experience could motivate students to self-develop a scaffolding approach to understand the practical constraints on real-life issues they confronted during the service-learning experience. Johri et al. [9] re-designed a freshmen course focusing on developing partnerships between colleges and international organizations to provide a scaffolding learning experience to undergraduate students, in which the positive influence of student motivation was tied to contextualized real-life projects.

However, interdisciplinary curricula or intercultural learning environments do not necessarily result in enhanced student motivation. For example, Wang [16] also reported that students’ learning motivation and professional skills can benefit from a course with combined efforts of multidisciplinary integration and problem-based learning implementation, which was supported by analytical results from pre-tests, mid-tests, and post-tests surveys. Though this project did include students from eleven countries, this intercultural learning environment was not considered as an asset contributing to the changes in students' learning motivation. Additionally, Zhu et al. [17] found no obvious impact of one multidisciplinary and cross-cultural course on students' motivation based on the analysis from the motivation survey. We should not assume a simple, certain, and direct relationship between the interdisciplinary or international elements and enhanced motivation. The key to raise student motivation likely lies in specific teaching practices or curricula design.

NSF IGERT program in sustainable electronics

This section provides an overview of the last cohort's experience in the IGERT program in sustainable electronics.

Class structure

The IGERT trainees were located at two different universities, separated by 670 miles. The trainees are required to take four classes that focus on sustainable electronics. The students in each university assembled in a classroom with at least one faculty member and the class was conducted through WebEx. The first two classes, Design for Global Sustainability I and II (DGS-I or DGS-II), served as the foundation for learning; topics included sustainability, general processing and manufacturing knowledge of electronics, and policies and regulations for waste management. The third class on life cycle assessment (LCA) focused on understanding the environmental and economic implications of products by monitoring all inputs and outputs of a system. The final class focused on applying the knowledge of the previous classes to a research topic of interest. This class looked different depending on the cohort as cohort 3 created their own class. Since the third cohort’s experiences are the subject of the present paper, this topic will be discussed in depth in the subsequent section in Examples of Student-Driven Programming.
**Domestic workshops**

Early in the first semester of classes, the students and faculty from Purdue and Tuskegee Universities visited three companies in Indianapolis. The goal was to understand the electronics supply chain and the role of sustainability in each of the companies and to give the members of the cohort an opportunity to meet and form deeper relationships than in distance collaborations during the class. This field trip was important for the IGERT cohort as (1) it was the first physical exposure to electronics manufacturing, recycling, and business strategy for most trainees, and (2) the students were able to interact with peers in an informal setting.

**International workshops**

The summer after the first year of the program was spent visiting different companies and organizations in India to learn more about electronics manufacturing, policy, and recycling. The students met with chief officers, owners, directors, workers, and students from various businesses, colleges, and non-governmental organizations near New Delhi, Jaipur, and Udaipur. For each visit, two students were assigned to lead the discussions and to provide the detailed information and context of the subject of matter to the group prior to the visit. The students learned how electronic materials are made, how electronic elements are mined and recycled, what it takes to build a successful business, how organizations give back to the community and much more related topics. To gain an appreciation and deeper understanding of what was learned or experienced throughout the day, the students would discuss and record critical incident assessments (CIA) as a group [26]. These assessments consisted of a structured discussion on a specific event that had some memorable or lasting impact where we thought valuable lessons could be learned or interesting insights could be shared.

**Examples of student-driven programming**

*Self-organized seminar course*

Design for Global Sustainability III (DGS-III) was a student-led seminar course expanding on prior knowledge concerning electronic sustainability. In this seminar, students taught each other about sustainable electronics topics relevant to their research and passions. Students developed the syllabus, prepared presentations and homework, and invited external speakers to derive maximal value from the course. For example, classes were composed of targeted group discussions, innovative sustainability seminars related to members' theses, and interacting with Congress where the class participated in lobbying with a member of congress. The opportunity for students to propose, design, and implement their own seminar course presented itself when the final structured class became logistically impossible for a portion of the distance learning students.

*Mentoring the LOREX students*

IGERT trainees advised approximately thirty students from different geographic regions participating in international research internships through the Limnology and Oceanography Research Exchange (LOREX) program at Umea University, Sweden. These internships are hosted at six different locations with the purpose of providing training in international research for graduate students. IGERT trainees advised these students on the concept and execution of a CIA to enhance cultural learning during their international experience. The CIA was subsequently adapted by the LOREX students into a blog post describing various incidents throughout their research experience abroad.
**Puerto Rico workshop**
Additionally, as the final workshop for the IGERT program, the same cohort of students planned a second field trip on their own to study resilience in the electronics supply chain in Puerto Rico after Hurricane Maria. The students designed a two-week pre-trip seminar course and were responsible for developing the syllabus, identifying learning objectives, locating the contacts, preparing learning materials for peers, building a trip itinerary, and leading the discussions on-site. The third cohort also invited all IGERT alumni to participate in the workshop in Puerto Rico.

**Methods**
There were 11 graduate students in the third cohort in IGERT who majored in materials engineering, anthropology, math, and environmental and ecological engineering at Purdue University or Tuskegee University when the traineeship started in 2016. A Qualtrics survey was developed to collect students’ opinions and feedback about the IGERT program in the context of student motivation through autonomy, competence, relatedness, and values. Survey questions consisted of matrix questions, Likert scale questions, ranking questions, and open-ended response questions which can be found in the supplemental information. The survey was distributed to the 9 students who were enrolled at the end of the program (cohort 3) and one student from cohort 1 who chose to participate in the Puerto Rico workshop. The authors received 9 responses (response rate 90%). Demographic variables such as gender and age were excluded from the survey.

**Results and Discussion**

**Internalization of student motivation**

*Value*

Students were asked about why they participated in three representative projects (India workshop, DGS-III, and the Puerto Rico workshop), arranged chronologically, during the program: was it because of their own interests, or the expectations from the faculty and peers? The options provided cover two major categories in motivation theory, i.e., intrinsic motivation (internal interests) and extrinsic motivation (external expectations). The results illustrated in Fig.1 reveals that the majority of the students were motivated by both intrinsic and extrinsic factors. Notably, the importance of the expectations from the faculty, an extrinsic factor in student motivation, showed a declining trend, indicating trainees being able to internalize extrinsic motivations at a later stage of the program. On the other side, the importance of the expectations from the peers, another extrinsic factor, increased for the seminar class and Puerto Rico workshop compared to the India workshop. A successful multi-year program may consider offering ample opportunities for students to internalize extrinsic motivation.
Figure 1: Overview of the changes in students' motivation for major self-organized projects throughout the IGERT program.

Figure 2: (a) The values of IGERT in sustainable electronics were well-perceived by the participants. (b) Students understood the three core values of IGERT in sustainable electronics deeper throughout the program.
As shown in Fig.2(a), all students responded they strongly agreed with the statement that the IGERT program was valuable; all students agreed that they could use the knowledge they learned in the program in the future; all students agreed that the training provided by the IGERT program aligned with their career goals and interests. Overall, the participants were able to see the value of the IGERT program from different perspectives.

To avoid ambiguity, three core values designed to be delivered by the IGERT program were explicitly described in the survey. Survey responses indicated a trend that students were more likely to agree with them after the program, as shown in Fig.2(b), which also suggests a successful teaching outcome of the IGERT program.

**Relatedness**

The majority of respondents believed that they shared a common vision and set of values with their primary advisor, and that their advisor shared a common vision with other faculty in the program (see Fig.3). Considering the sheer number of different disciplines from engineering, economic, and societal sectors involved in the program and the non-traditional format of its structure, it is fair to claim that the IGERT in sustainable electronics program offered a cohesive and positive learning environment.

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**Figure 3:** (a) Values that between students and faculty and between faculty and program are in great alignment, creating a benign environment to grow relatedness within the program. (b) The majority of the students started to see the shared value among the cohort after the international learning experience in India or the collaborative projects required in an interdisciplinary course.
As previously shown in Fig.2(b), the trainees' value evolved with the program. It is, therefore, of interest to investigate what projects made students start to realize a set of shared values with their peers and how this transition occurred. As shown in Fig.3(b), the majority of the participants identified the India workshop as the turning point. Three students responded that they started to see the shared values, earlier than the India workshop, during the collaborative project of DGS-I, upon finishing the first semester.

**Competence**

Comparing the competence factor of student motivation in an early learning experience, the India workshop, and a final experience, the Puerto Rico workshop, the responses in Fig.4 exhibited a strong trend of increasing competence in participating in group activities over their tenure in the IGERT program. For the three activities surveyed, most students reported that they felt confident or qualified to participate in group discussions, lead group discussions, and schedule and plan meetings during the Puerto Rico trip. Whereas for the India trip, the positive responses in each question were notably lower.

**Figure 4:** Near the end of the IGERT program, students were more confident and qualified to participate in various activities including the planning and preparation of optional projects beyond the original programming. Students reported a higher level of confidence in dealing with projects at a later stage due to previous collaborative experiences.

Most students agreed that they felt more qualified to participate in, develop, and plan the Puerto Rico workshop due to previous learning experiences in the IGERT program, (see Fig.4).
India workshop is classified as one of these educational experiences which promoted future growth.

The results shown in value Fig. 1-4 demonstrate that the IGERT trainees and faculty possessed a common set of values that not only existed when launching the program, but also were reinforced by the program. Those values, originally being intrinsic motivation, later echoed with internalized extrinsic motivation [10], [11]. A relevant question is when and how the internalization of external values and the conceptualization of shared values took place in current teaching practices. The results shown in Fig. 4 shed light on two potential answers: collaborative, problem-based learning (the final project of DGS-I) and intercultural experiences (India workshop).

Guided international experiences

The purpose of the India trip was to gain an understanding and appreciation of all the stakeholders in the global electronics supply chain. Meeting with people from NGOs, businesses, and other organizations gave the IGERT cohort a thorough understanding of the work necessary to build electronic products, uphold policies, or manage international businesses. Not only was discussing business logistics with upper management and observing the labor of employees educational from an academic perspective, but the meetings also allowed for an appreciation of the influence of corporate social responsibility (CSR) on the community. An equally important aspect of the trip were the discussions, both extemporaneous and those generated by the CIA forms. The perspectives introduced in these discussions were not always similar, and it was valuable to have an educated and constructive conversation about shared experiences. By the conclusion of the trip, the IGERT cohort was able to gain an understanding of employee-employer relationships, effective corporate models, and the impact of policies and education on the environment. These lessons directly relate to our understanding of electronics sustainability – socially, economically, and environmentally.

The India workshop, as shown in Fig. 4(b), helped the majority of the last cohort realize the shared value with the group. Some earlier studies on international experiences that had a positive influence on student motivation may provide insights on what IGERT's India workshop did correctly. Arzberger et al. [1] provided an all-round analysis of PRIME (Pacific Rim Experience for Undergraduates), a four-year international, research-oriented, and sustainable program. The goal was to train undergraduate students as global professionals and equip students with global citizen mindsets through collaboration between research institutes and industries across cultures and disciplines. One key feature of the PRIME program is that students are required to initiate the discussion on potential research topics they are interested in with mentors. In another study, Layer and Gwaltney [23] reported an international capstone program in which students were bestowed with a sense of difference-making when they completed the assigned projects, as those projects originated from actual industrial or societal needs. The study considered many cultural aspects, such as cultural awareness, as both inputs and outcomes. Meanwhile, the post-project survey demonstrated a substantial increase in students' understanding of attributes that are indirectly related to intercultural differences such as global awareness and emotional experience. Particularly, the motivation attribute (i.e., students’ motivation to learn) was significantly enhanced in this learning experience.
The emphasis on group discussion, global citizen mindsets, and cultural awareness in these two studies resembles the purpose of the IGERT India trip. As earlier introduced in the background section, the students were required to discuss and record critical incident assessments (CIAs) as a group on a daily basis to gain a deeper understanding of incidents taking into consideration cultural differences and emotional responses [24]-[26]. More importantly, the IGERT India trip aimed to prepare the students with toolboxes for navigating cultural differences. Though no students identified this preparation work (pre-meetings and presentations) as the turning point, it is an essential step in laying the groundwork for effective learning. The planning of the trip in which few students participated, was carefully handled by the faculty so that students would visit companies or organizations in India that were similar to the previous visits in the U.S.A. Building the connections between clustered experiences ensured the quality of this intercultural learning experience, which reflected Dewey’s classical philosophy on experience and education [27]. By the end of this trip, the last cohort had insightful discussions on almost every aspect of the trip including similarity in corporation models, differences in culture, and inspiring businesses with a dedication to the community in relation to economic, environmental, or social sustainability. Several responses from IGERT trainees on the India trip collected by our survey are quoted below:

"The IGERT India Trip on a whole was certainly a defining moment of my educational experience, ... the numerous opportunities to meet with stakeholders first-hand, and to see various aspects of the electronics supply chain in person, were invaluable in bringing the concepts we had studied into concrete terms and highlighting the urgency and importance of working toward sustainable practices."

"I don't think I saw how any of the knowledge we had been taught in class really applied until we went on the India trip. Everything we saw on our domestic trips while providing insight, was kind of what I expected it to be... This trip made me realize the bigger picture and the severity of the challenges faced in..."

"For instance, visiting Heritage [in a previous domestic field trip] was really inspiring to me because... This (same) idea was seen multiple times in India where it is much easier due to lower regulations to use..."

Shared value, or relatedness, is likely to be conceptualized with intercultural communication of scientific outcomes that were cultivated via sequential training on cultural awareness and stakeholder perspectives taking place throughout the entire program. Student-initiated discussions or reflections through the adapted methods of CIA provided a supervised and secure space for this communication to occur.

**Integration of problem-based learning (PBL) in interdisciplinary curricula**

The DSG-I project marked the first collaborative experience for the IGERT trainees in a professional setting. The final project of DGS-I was named "Project X," meaning the students were free to choose any subject-matter, as long as the subject was under the electronics umbrella, for this collaborative assignment. The goal of the semester-long team research project is to apply
the sustainability concepts learned in the classroom or self-study to a specific class of electronic products. Students were required to analyze the product "X" in terms of societal, environmental, and industrial/economic sectors, and the opportunities for greater value recovery. Naturally, students considered real-life questions such as how it was designed by the engineers, how it was sold by retailers, and how it was used by the customers and the real-life challenges caused by any of those questions.

Perhaps because the majority of current interdisciplinary programs and project/problem-based learning cases aim to bring real-world challenges into the classroom, an overlapped region clearly exists between the two research fields [18]-[22]. For example, Kuo et al. [19] proposed the concept of Interdisciplinary Project-Based Learning (IPBL): Motivated Strategies for Learning Questionnaire which was used to evaluate the participant’s perception of learning motivation via three subscales: self-efficacy, the joyfulness of learning, and valuing the significance of learning on future career development. Within the time frame of 18 weeks, guided by design thinking, the IPBL approach was reported to have significant impacts on student's learning motivation. Bischof et al. [22] argued that project-based learning employed in mathematics courses would be especially useful to engineering students because it is crucial to have engineering students understand how mathematics can help them with their future studies and professional careers. The selected problems all included at least one section needed to be solved with mathematics knowledge that was slightly beyond their current abilities. Confronted with those challenging problems, students realized the gaps between their understanding of engineering mathematics and the knowledge required to solve real-life problems with industry (for example, joint research with BMW). This realization, in turn, motivated students to devote time and energy to learn mathematics. Note that this program carefully re-designed the curriculum of engineering mathematics so that its contents were of students’ interests and could be directly applied to their future studies.

One of the written responses from IGERT participants, when asked what aspect was most valuable, also provides evidence to Bischof’s conclusion [22]:

"The work I conduct within my program department (Mathematics) is highly specialized and very technical in nature, and it can be very easy to lose sight of practical applications... The IGERT program provided a much-needed opportunity to expand my research perspective and helped to open my mind to a number of different interdisciplinary research collaborations that broadened the scope of my research and thinking in general."

For an interdisciplinary curriculum, apart from educational institutes, other collaborators include government agencies, industries, and nonprofit organizations. Under the framework of project-based learning, the program not only introduced real-world issues to students, but also sought opportunities to transfer students’ solutions into applications, which in turn, would help students see the value of the projects and see the shared value among peers, and ultimately motivate students by building the value system and group relatedness within the program.

**Autonomy**

In the India workshop, students were more involved in passive learning experiences (participation in the group discussion) compared with active ones (planning of the activities). To
investigate the role autonomy played throughout the program, students were asked if they felt they had control over the IGERT program. These data are shown in Fig.5(a). Autonomy as a salient feature in the IGERT program is evidenced by the overwhelmingly positive feedback. Most students picked "upon finishing the second-year courses" as the time when they felt autonomy in the IGERT program. The students reported the IGERT self-designed seminar course (DGS-III) as the most helpful project to develop their sense of autonomy. These data are consistent with a growing sense of autonomy regarding the planning of shared experiences, also shown in Fig.6(a).

**Figure 5:** (a) All students believed that they were involved in the design of the IGERT program. (b-c) A large portion of the students identified the self-designed seminar course as the starting point.
Figure 6: (a) Students were more involved in later learning experiences than earlier ones. (b) Students actively participated in the preparation and planning of the self-organized seminar course and self-organized Puerto Rico field trip.

To tie the students’ feeling of autonomy to specific projects, students were asked to select their participation in activities related to the IGERT programming. Students reported more autonomy with developing and logistically planning their learning objectives over the duration of the IGERT program, as shown in Fig.6(b). For example, of the students who participated, some students felt involved in the India workshop planning, most students felt involved in the seminar class planning, and all students who participated felt involved in the Puerto Rico workshop planning. A slow, but steadily increasing exposure to autonomous behaviors may help facilitate motivation regarding new behaviors and experiences. A steadily increasing exposure first introduces students to a working knowledge of the subject. After a basic understanding is developed, allowing creative adaptation of the main goals of the project can help students redefine these goals in their own terms. This creative adaptation is the autonomy necessary for motivation – having a clear concept for how to proceed. The IGERT program helped to facilitate autonomous feelings and behavior in the students by having them create and refine their learning objectives after having a working understanding of where this experience ties into the goals of the program.

A sociocultural context

The aspects of the IGERT program that students found most valuable are ranked in Fig.7. Weighted scores were summed up for each aspect on the right hand side based on the criteria that ranking #1 to #6 were assigned with values from 6 to 1. We found that students most valued
intercultural workshops and peers. When ranking components of the IGERT program against each other, over half of the students reported intercultural workshops as either number one or two and one-third of students reported peers and either number one or number two. Note that the option of intercultural workshops, in the context of this survey, includes both the trips to India and Puerto Rico. Courses, domestic field trips, and faculty mentorship were ranked after the previous three. Bi-annual workshops at Purdue University and Research Experience for Teachers (RET) were ranked the lowest within the last cohort. One reason for RET being the least favorable factor may be the limited number of students who participated in the program.

Figure 7: International filed trips were highlighted by the rating on the most valuable aspects of the IGERT in sustainable electronics program that were perceived by the students.

Internalization is the reconstruction of external operations from internal minds [28], which occurs through the interactions between learners and their social and cultural context. Effective teaching in school, which is primarily a social environment, is impossible without the realization that individuals are inseparable from their sociocultural setting [29]. This importance of the social context in the IGERT program can be partially shown in Fig.7; International trips, peers, and courses were ranked as the three most valuable aspects of the IGERT program. An international trip than can contextualize the cultural materials of the subject and a learning community that encourages collaboration on projects rooted in real-life challenges are critical yet may be easily overlooked compared with other factors such as the faculty mentorship. In fact, when backing the choice to the question "which project helped you see the shared value the most?" a student wrote the following statement:
"Actively teaching my research and topic of interest to peers and making my own connections to the shared IGERT values, especially where obligation from professors was not an influential factor in developing my discussion topic (I could choose whatever I wanted to share and teach my peers)."

The quote pointed out that a social environment without external influence (obligation from professors) grants autonomy described in the self-determination theory [10]. This principle can also be traced back to the educational philosophy "Democracy and Education" established by Dewey a century ago, that the education is between the self-realizing pupils and their external social context in which no presupposed fixed end exists [30].

An initiative taken by the IGERT program is allowing the last cohort to self-design the final course, which was specifically organized to create a symbiotic teaching/learning environment between the IGERT trainees. Instead of a traditional lecture-style class, this class was developed to enhance learning and discussion by having each class taught by one of the trainees in a facilitating environment. The trainees presented lectures, discussion topics, and/or other interactive material directly related their main thesis work to the rest of the cohort, and clearly presented how the material learned in the previous courses were able to enhance their research. These in-depth, relevant topics helped the trainees expand on their knowledge formulated in the three previous courses. With the entire last cohort having agreed that they were part of the designing force of the IGERT programming [see Fig.5(a)], this self-organized course was deemed as the turning point when the feeling of autonomy became dominant in more than half of the students [see Fig.5(b)]. This course’s profound influence can also be decoded from Fig.8(a) in which the number of the students who felt involved in the planning of this course was twice that of the earlier India workshop. Digging deeper into what specific tasks were taken by the students in Fig.8(b), it reveals that nine students were involved in the design of the learning outcomes and syllabus for the seminar course. Indeed, a deeper understanding and appreciation of learning outcomes exposes students to the "whole game" instead of scattered pieces of knowledge within the individual disciplines [13], [31]. This may be especially true for interdisciplinary (or multidisciplinary) curricular development as the knowledge roots in mixed backgrounds and fields.

However, promoting student autonomy does not mean eliminating faculty mentorship. Koch et al. [32] concluded that a differentiated support system or agency from the faculty side can substantially help fulfill students’ psychological needs and academic performance. When providing the reasoning for the ranking of valuable factors, one IGERT trainee’s responses pointed out what types of support from faculty were most effective:

"There is a difference between faculty in general and [the PI], who was emotionally encouraging, financially supportive, and willing to take initiative contacting the correct individuals to facilitate many of our group ideas. So although "support from faculty" is listed as moderately important, I would rate "support from [the PI]" as extremely important."

This student’s reflection demonstrates that specific types of support can be immensely valuable during the learning process. In fact, while planning and organizational responsibilities fell increasingly on students (as evidenced by the participation in Fig.8) students still received faculty mentorship throughout their planning process- in an instructional capacity as well as
emotional. When asked whether the group’s initiative came from situational happenstance, the student responded:

“I believe we were able to effectively execute the Puerto Rico workshop because [the PI] believed we would put in the effort needed to make it happen...”

In addition to other factors listed by the student, the PI’s emotional support or belief in their success was one of the reasons that the student felt the cohort could take initiative beyond the scope of the original programming. Therefore, promoting autonomy needs the combined efforts from both the faculty and students. For the former, the defining element in an educative mentorship is the effort to promote self-realizing personalities, a wider sociocultural context, and an interactive learning experience. If applicable, instructors may consider, to some extent, allowing students to participate in the design of the learning outcomes, if not completely.

A learning community

Peers and team projects, two of the factors that were identified as highly valuable (see Fig.7), are fundamental contributors to positive group dynamics. The survey targeted the exact aspects that students felt made a more motivating group dynamic for the last cohort. When asked the most important components for the cohort taking initiative beyond the original scope of the IGERT program, the students identified group proactivity, cohesiveness, and attitude in their peers as being the most important (see Fig.8). In fact, the majority of the factors listed in the survey were perceived as least moderately important. The only variable that received less positive feedback is the group career goals, i.e., if the group's shared ambitions, to some extent, aligned with the IGERT program. The dominating positive responses again support the importance of peers and collaboration among peers.

Figure 8: Students' rating on the importance of different factors in promoting self-determination within the last cohort of IGERT in sustainable electronics program. Group proactivity, group cohesiveness, and group attitude were rated as the three most influential factors.
The group dynamic, defined here as the combination of the peers and the collaborations on team projects, is the second most important factor in the IGERT program (see Fig.8). A learning community itself is a space outside the individual’s zone [28]. The authors singled out the learning community from the rest of the sociocultural context because it represents a profound educational philosophy that advocates for the construction of knowledge [27]. In an earlier quotation, a student responded that "I could choose whatever I wanted to share and teach my peers." Indeed, selecting, sharing, and teaching a topic to peers is a representation of learning outside the zone in which an individual interacts with external perspectives or different understandings of a topic, i.e., the zone of proximal development [29]. With this cognitive development, a higher level of learning process and constructive and interactive learning can be achieved [33].

Therefore it is also important to note the influence of external motivation due to the social environment developed by peers, yet this influence may be both beneficial or detrimental in certain circumstances. If verbally aggressive individuals are highly vocal in a group, this aspect may be de-motivating to peers. Conversely, in a supportive and positive environment, peers can be beneficially impactful for the motivation of those around them. For example, when asked their opinions about the valuable aspects of the IGERT program, one written response was:

"... specifically, open-minded peers with the same attitude and encouragement are very important to me and I ranked as number 2. Peers who have negative attitudes and are not encouraging are also important, however I would rank these peers below courses."

Based on our teaching practices, the answer to the question "when and how to start to build a learning community" is: the earlier the better. For situations where students lack the opportunities to be in the classroom or space, educators should strive to find opportunities for students to meet physically.

**Conclusion**

The NSF IGERT in sustainable electronics nurtured value, relatedness, competence, and autonomy in the final cohort which aligns with the self-motivated activities or initiatives taken by the participants. Students experienced the internalization of external values, during which the guided international learning experience in India and the self-organized seminar course are of great importance for developing relatedness (shared value) and student autonomy within the learning community. The last cohort rated the international trips as the most valuable aspect of the IGERT program, which included the India workshop organized by the faculty early in the program and the Puerto Rico organized by the students a year later. Students exhibited a higher level of competence, autonomy, and relatedness during the latter trip, implying the successful learning experiences designed and delivered by the IGERT program.

Lessons learned based on our teaching experiences can be concluded as the following:

1. Project- or problem-based learning theory can be easily adapted into interdisciplinary curricula, which is beneficial to student motivation for the students can better grasp the value of the knowledge taught
2. Intercultural communication promotes group cohesiveness if a learning community is involved. An effective way to achieve an authentic intercultural learning experience is international workshops with coherent training on cultural awareness and student-led reflective discussions.

3. It takes a combined effort from the faculty side and the pupil side to build a self-motivating learning community. Students should be given ample opportunities to connect with peers and spaces in participating in the design process of either projects or curricula. Faculty mentorship and support are essential during this process.

Limitations

As a non-experimental study (survey research) that is also based on the observation of students' performance. It is not easy to survey all the variables involved, so we selected and surveyed four variables that likely played key roles after multiple reflective discussions. The authors inevitably imposed assumptions on the survey environment, e.g., variables such as "cost" and "expectancy" were excluded, though included in other studies of the motivation theory. The survey was distributed to the 9 students who were enrolled at the end of the program (cohort 3) and one student from cohort 1 who chose to participate in the Puerto Rico workshop. The authors received 9 responses (response rate 90%). Demographic variables such as gender and age were excluded from the survey. Arguably, the sample size is relatively small to make decisive conclusions. Therefore a more qualitative approach was adapted in the survey whose results were interpreted based on trends and compassion. Ideally, comparing and contrasting need rigorous pre-and-post tests. Yet this work is another initiative taken by the last cohort of the IGERT thereby no pre-intervention test was available. To partially compensate for the lack of pre-intervention data, multiple survey questions were constructed to capture and investigate the student reflection before and after the IGERT program. This survey study is more appropriately deemed as a descriptive and reflective case study of teaching practices in real-life settings rather than rigid experimental research. Obtaining a deeper understanding of contextualized relationships between suggested curricula design and expected performance is beyond the scope of this work.

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