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Transforming Learning Orientations Through STEM Interdisciplinary Project-Based Learning

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Abstract: Science, technology, engineering, and math (STEM) education is challenged by industries to incorporate business, engineering, and communication experiences to prepare students for workplace success. In this study, we outline an approach—the STEM Oriented Alliance for Research (SOAR)—to enhance student experience by offering interdisciplinary project-based learning (IPBL) for undergraduate students majoring in electrical engineering, communications, and marketing. We examined how students' disciplinary and cooperative orientations toward learning shifted in response to their experiences in a semester-long interdisciplinary project-based learning experience with authentic industry outputs. Using a multi-method approach, we explored how interdisciplinary projects influenced student experiences in terms of five collaboration abilities: positive interdependence, accountability, promotive interaction, group processing, and social skills. Further, we observed a shift from fixed- to more growth-oriented mindsets, and from a primarily disciplinary to interdisciplinary focus for their future professional work. The outcomes of the SOAR project make clear that providing structure for professional cooperation on interdisciplinary projects can have profound effects on how students learn to cooperate and position themselves as learners. For most SOAR participants, the experience was deeply formative and contributed to their readiness to cooperate and learn within the interdisciplinary and STEM-oriented workforce.

Keywords: project-based learning; cooperative learning; interdisciplinary learning; mindset; STEM

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1. Introduction

In this study, we examine important outcomes of an evidence-based and industry-modeled interdisciplinary project-based learning initiative intended to engage undergraduate students as professionals who can innovate, collaborate, communicate, and work skillfully and diligently across domains [1–5]. The rapid social and economic change occurring as we experience a fourth industrial revolution requires exploration of project-based learning in interdisciplinary settings that can enhance student engagement and understanding, particularly in STEM [6]. Given the high demand of the benefits of project-based learning on student development, including skill enhancement, teamwork, and critical thinking, project-based courses can improve students' collaboration skills and overall learning experience [7,8], and higher education is challenged to create frameworks for project-based learning effective across disciplines [9].

Some industry initiatives such as Google's Oxygen and Aristotle programs provide evidence that interdisciplinary teams composed of professionals from various fields can enhance both work processes and products [10,11]. To encourage interdisciplinary research

and collaboration in STEM, business, and liberal arts fields, which are our respective areas of expertise, we have extended evidence-based models. Our goal is to introduce interdisciplinary principles to college classrooms by creating an environment that fosters cohesive interaction centered on real-world problems. This research details the STEM Oriented Alliance for Research (SOAR), a project-based interdisciplinary initiative, and examines its impact on undergraduate students. We designed a transformative educational experience that promotes interdisciplinary understanding, collaboration, and a growth mindset, enhancing students' skills, knowledge, satisfaction, and confidence to engage as modern professionals.

1.1. Theory of Action for Interdisciplinary Project-Based Learning

Several overlapping and research-based educational practices underpin the design of the SOAR project and the hypothesized educational and social outcomes of students' participation. A theory of action for interdisciplinary project-based learning guided this work and our examination of outcomes. We drew from decades of research on project-based [12], cooperative learning [13], interdisciplinary learning [14], growth mindset [15], and formative assessment [16,17], to describe processes and outcomes of educator and student actions within interdisciplinary project-based learning.

In the theory of action, educators initiate interdisciplinary project-based learning through planning for diverse teams comprising of multiple disciplines. This planning includes defining interdisciplinary products, identifying goals, information collection opportunities, supports for students' self-directed efforts, opportunities for student ownership, activation of peers as resources for one another, and considering when feedback on student efforts will be appropriate. Altogether, these combined efforts have the potential to increase student learning, cooperation, learning mindset, and interdisciplinary understanding as students work to build quality products together. In the sections below, we highlight research around interdisciplinary, project-based, and cooperative learning, mindset, and a formative assessment process that underpin the theory of action informing our study.

1.1.1. Interdisciplinary Learning

It is often challenging for scientists and engineers to convey or explain their knowledge and concepts to non-experts without any engineering background [18]. On the other hand, business, and communications professionals are often equally challenged to describe or communicate topics and ideas in science and technology. Despite initial challenges to interdisciplinary learning (e.g., shared language, disciplinary techniques), the benefits are wide-ranging, including the potential for generating new knowledge, meaningful collaboration, and new relationships [19,20]. Further, interdisciplinary learning can enhance students' awareness of interconnectivity among disciplines, innovation, and creativity [14,21,22]. Finally, by engaging students in cooperative cross-disciplinary work, peers and educator teams can develop trust and confidence in one another and make work more fulfilling [23].

1.1.2. Project-Based Learning

Project-based learning is experiential education that places value on student-led creative and goal-directed efforts and outputs [24]. When compared to traditionally passive lecture-based courses, active and project-based STEM courses contribute to higher student achievement [25]. If used effectively, project-based learning can also promote students' positive perceptions of their own skillsets, the utility of courses, and students' interest in pursuing STEM-oriented careers [26]. To achieve these benefits, [12] described the essential elements of project-based learning including promoting critical problem-solving, creativity, and the refinement of work and skillsets across time. However, [27] found that individual characteristics (e.g., attitudes, behavior, learning approaches) and group cultures (e.g., finishing culture vs. collaborative learning culture) that groups bring to collaboration

impacts the depth of learning in groups. Cooperation among group members can impact the learning process and products made.

1.1.3. Cooperative Learning

Teams without structure can lead to conflicts, disparate contributions, and mismanagement of tasks [13]. Cooperative learning is needed for students to learn from interaction while working as a team and to complete tasks and achieve shared goals that individuals could not complete alone [28]. Structured effectively, cooperative learning can have many positive impacts on students, including on achievement, motivation, and peer relationships [29,30]. Ref. [13] outline five essential components to successful cooperative learning: positive interdependence, promotive interaction, individual accountability, interpersonal social skills, and group processing.

First, groups need to be arranged in such a way as to promote positive interdependence—delineated roles for each person to contribute and take responsibility for an aspect of the work. Another key aspect of successful cooperative learning is promotive interaction. Here, encouragement, helpfulness, the provision of feedback, and constructive work together helps a team be successful [31]. A third component is individual accountability. When students feel responsible for contributing to the group and that their contributions are identifiable in the products of their work, it is more likely each group member will make the effort [13]. Fourth, interpersonal social skills are essential. This includes the abilities to communicate, actively listen, participate in democratic decision-making, and manage potential disagreements. Each of these are vital to ensure students respect one another and make progress toward goals together [13]. Finally, group processing involves the inclusion of all in discussions, decision-making, and the establishment of group norms. This final component is essential for the group members to identify as a collective whole [32].

1.1.4. Mindset

There are barriers to learning including preconceptions, predispositions, and mindsets students bring with them, which prevent students from fully realizing the full potential of learning experiences [27]. Reference [15] described the mindsets learners bring to educational experiences as a continuum from a fixed to a growth mindset. A fixed mindset is characterized by rigidity in approaches to learning—potentially equating intelligence to talent and avoiding risks or challenges. Individuals with a fixed mindset may believe that they possess (or do not) the skills necessary to do a task and may be less receptive to growth-oriented feedback and redoubling of efforts to achieve a goal. These individuals are more likely to quit when faced with challenges and achieve less than their growth-oriented peers [33]. A growth mindset is exemplified by positioning effort and engagement as the key to achieving success and may consider intelligence to be malleable. Individuals adopting a growth mindset may approach challenging tasks iteratively—trying out strategies, seeking feedback and further opportunities to challenge themselves, and learning from mistakes [33].

2. The SOAR Project

We incorporated evidence and guidance for effective practices into the design of the SOAR project—an interdisciplinary project-based learning initiative that engages a team in bringing a product to market. These projects centered around a prototype developed by electrical engineering students (e.g., an airfoil glider electricity generating system, a current calibration coil). The SOAR project emulated an industry setting with a series of assignments, multiple checkpoints, and feedback. This project also allows students to develop team-building abilities and collaboration skills. Throughout the semester, students are asked to reflect on their group's interdisciplinary collaboration and project overall (see Figure 1 for project timeline, deliverables, and surveys). Students had to complete four modules; each module required specific group tasks along with rubrics. Groups needed to:

1. Identify stakeholders, broader impacts, team roles, a timeline for completion, and a joint statement synthesizing the project.
2. Provide a research-based description of their product's significance and rationale, a product, and a market description.
3. Present a business pitch to communicate their product to an audience of clients, investors, and other stakeholders.
4. Create a press release, a written and performed product pitch in a shark tank-style format, and a video.

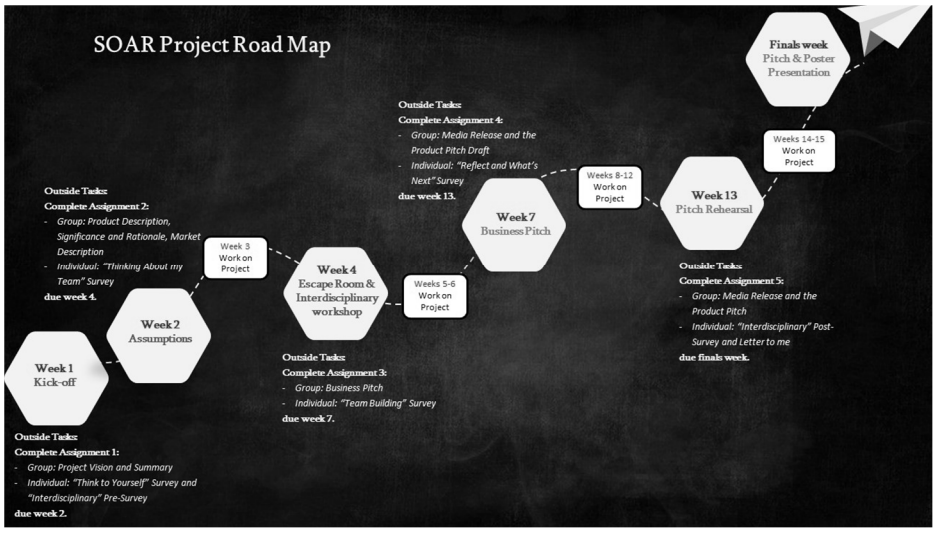


Figure 1. SOAR project road map.

After each module, groups submitted their work to the interdisciplinary teaching team where they received feedback based on the criteria for exemplary work and were given an opportunity to implement feedback into their progressive portfolios. At the end of the course, each group submitted final portfolios that displayed their best work (see BLINDED for a full description of the SOAR program including development and piloting).

3. Present Study

Study Objectives

To explore the interdisciplinary and cooperative learning orientations of groups of engineering, communications, and business/marketing students, we collected artifacts and analyzed students' reflections on their cooperative interdisciplinary project-based learning experience. The following questions frame our study:

1. How does the SOAR program impact cooperative learning orientations of students over the semester?
2. What dispositions and mindsets toward interdisciplinary learning are exemplified in student reflections?

4. Methods

This descriptive study drew on survey reflections to understand the impact of the SOAR program on interdisciplinary understanding, cooperative learning, and student dispositions and mindsets over time. We elicited authentic and anonymous reflections on groups and projects. We analyzed outcomes over time to better understand how students perceived their experiences throughout the project.

4.1. Participants

In Spring 2020 at a university located in the United States, we had a total of 51 students comprising 22 business-majored, 14 communications-majored, and 20 engineering-majored

students who were tasked to work on seven industry-sponsored projects over 15 weeks (8 weeks for business students). Examples of industry sponsors include Boeing, Fluke, and OceanGate, and each group consisted of a range of 8 to 13 students. This study was reviewed and approved by our institution's Institutional Review Board to collect data without identifying information. All participants gave consent to participate.

4.2. Data Sources

We used a questionnaire and five open-ended surveys to elicit student reflections on their interdisciplinary team collaboration over time.

4.2.1. Disciplinary, Interdisciplinary, and Collaboration Questionnaire

During the first SOAR session, we used a synchronous polling site to elicit anonymous responses to six questions. Students (n_{Range} = 34–40) rated their knowledge of their own major, perceptions of what people from other majors know about their area of study, and their collaboration abilities (1 = poor, 4 = excellent). Students also reported their motivation to collaborate and do well in the project (1 = not motivated, 4 = very motivated). Finally, students chose their greatest concern for interdisciplinary collaboration (i.e., group dynamics, unequal work, time constraints, conflict, or other) and what they value most in collaboration (i.e., gaining new perspectives, improving collaboration skills, improving communication skills, gaining career skills, or other). These questions were developed following open-ended feedback from an earlier iteration of the SOAR project.

4.2.2. Reflections

Students provided their own reflections on group roles, aspects of interdisciplinary learning and collaboration, goal setting and achievement, and reflective thinking on experiences throughout the project (Table 1). The questions were created and reviewed by a panel of experts to ensure the validity of the measurement.

Table 1. SOAR reflections.

Reflection	Prompts/Description
1	• What does an {Electrical Engineering, Communications, Business} major do? • What are their strengths for your project?
2	• Explain in a few sentences the role you perceive your team members to have. What do you expect each person will need to do to ensure your team's success? Complete this for all team members including yourself.
3	• How has your understanding about other disciplines changed? • How is your team interdependent? • Does each member contribute toward your goals? Why or why not? • How have your individual roles contributed to your success and/or failures as a team? • How has your group functioned overall? Explain please. • How have your social skills contributed to communication, clarification, and encouragement of team members? • What is the interaction between members of your group like? • Overall, what can you and the team do together to ensure you meet your goals?
4	• How did your team members do on their pitches? • What information did your team consider in making decisions for the final pitch? • Reflect how your team will do on the rubric, as of this moment. • How confident are you about your team's success? Why or why not?
5	Write a "Letter to Me." In it, write to yourself on the first day of the semester. Give advice to yourself. Consider assumptions you had about others, things you have learned, and things you would have done differently. Encourage yourself to take on challenges and explain ways to approach them. The letter should be between 1-2 single spaced pages.

Reflection 1. Within the first two weeks of the project and after the first interdisciplinary session, we elicited students' (n = 42) initial understandings of what people in electrical engineering, communications, and business majors do. After each major, prompts ask students to write what they see as disciplinary strengths for their group project.

Reflection 2. Between the second and fourth weeks of the project, we elicited student (n = 37) reflections on their team's organization and expectations. Specifically, we asked students to explain each person's role within their team, and their expectations for contributions from that person that would make the team successful. For example, roles include meeting arrangement, facilitating communication, making PowerPoint presentations, creating videos, or conducting market research.

Reflection 3. Between weeks four and seven, after completing their business pitch, students (n = 36) were asked to comment on how their understanding of other disciplines had changed, and to reflect on aspects of collaboration within their team. Finally, we asked students to comment on what the group needs to do to reach their goals.

Reflection 4. During the period of preparation for the final pitch (weeks 7–13), students (n = 37) responded to five questions eliciting their perception of their team's performance, how effective they were, and future team achievement.

Reflection 5. In the final reflection in weeks 13–15 and just before the product pitch and poster presentation, students (n = 38) wrote a 'letter to me'. This was a letter to the students themselves—the person they were on the first day of the semester. Students were prompted to offer advice, reflect on the assumptions we held about others, share the valuable lessons that they have learned, contemplate on the things they would have done differently, and provide encouraging words to embrace challenges while suggesting effective approaches to overcome them. A writing prompt and rubric were provided to guide their writing.

4.3. Analysis

With a focused attention on our research questions, an in-depth analysis of the questionnaire responses and thoughtful reflections, we have been able to draw meaningful inferences regarding how students perceive disciplines and their orientations toward learning and interdisciplinary groups. Responses to the questionnaire were summarized by the proportions of responses to questions and summarized in relation to other items (e.g., knowledge of one's own major and perceptions of others' knowledge of their major). To make sense of the information from reflections, we iteratively and recursively read responses and assigned codes to the data—assigning (or using participants' own words in vivo) words and phrases to describe qualitative information [34]. We drew from current information in data but also imposed codes to capture theoretical variables of interest (e.g., disciplinary, and cooperative orientations [34]. Through discussion and collaborative coding, we established a coding and scoring scheme to characterize emergent themes quantitatively. Using the coding scheme, two members of our research team coded all responses and made notes about feasible alternative codes and borderline cases. Both coders met and discussed discrepancies, resulting in full agreement. The coding scheme was presented and discussed with the full research team. Following discussion and critique, all responses were reexamined with the final coding scheme to ensure criteria and codes were consistently applied.

In all reflections, we coded for disciplinary/interdisciplinary orientations and facets of cooperative learning (i.e., positive interdependence, individual accountability, group processing, social skills, and promotive interaction (Table 2)). For cooperative learning orientations, we looked across each participant's responses to prompts within a reflection occasion and determined the degree of collaboration present in the responses (0 = N/A, 1 = some evidence, 2 = abundant evidence). For instance, if we found a single reference to either positive relationships with group members or acknowledging the contributions of group members, this response would receive a score of 1 for positive interdependence. If we found multiple references to establishing and enacting group goals and interaction among the group to meet goals, a response received a score of 2 for group processing. In the final

reflection, which took the form of a 'letter to me', we conducted coding to examine various aspects. First, we analyzed whether students mentioned their initial confusion or difficulty in understanding the SOAR project. Additionally, we looked at how students described their initial and final dispositions toward working in groups, categorizing them as positive, negative, neutral, mixed, or characterized by nervousness. Furthermore, we explored the mindsets toward learning apparent in the letters, such as differentiating between a growth mindset and a fixed mindset.

Table 2. Descriptions of cooperative learning.

Element	Description
Positive interdependence	Positive relationships and contributions of group members
Individual accountability	Dependence of each group members' contributions
Promotive interaction	Mutual encouraging and facilitated communications
Group processing	Group functioning through the establishment and enactment of goals, and interaction
Social skills	Interpersonal communication skills (e.g., clarification, gratitude)

Note: Adapted from [35].

5. Results

We examined SOAR students' orientations toward disciplines, group cooperation, the project, and learning over a fifteen-week semester (eight weeks for business students). We report on our first information collection occasion, and themes identified in reflections over the semester. We provide descriptions of themes and exemplify them in students' own words.

5.1. Disciplinary, Interdisciplinary, and Collaboration Questionnaire

At the onset of the SOAR project, we observed patterns in students' perceptions of their own disciplinary knowledge, positioning of their peers' knowledge of their major, as well as project motivations and concerns (Table 3). Unsurprisingly, most students rated their knowledge of their own discipline highly, however, they rated their peers' knowledge of their major lower. On average, students rated their interdisciplinary knowledge as fair or good, but in rating their abilities to collaborate, most students rated themselves highly—good or excellent. All participants were motivated or very motivated to do well in the project. Considering their upcoming interdisciplinary project collaborations, we found students were concerned with potential time constraints (n = 14, 41%), group dynamics (n = 11, 32%), and conflict (n = 3, 9%)—six (18%) listed that they had other concerns. Finally, students responded to a question about what they valued most in collaboration. Students reported they hoped to gain new perspectives (n = 15, 38%), gain career skills (n = 10, 25%), improve collaboration skills (n = 5, 13%), and improve their communication (n = 5, 13%) skills. Five (13%) said they retained other values for collaboration.

Table 3. Disciplinary, interdisciplinary, and collaborative questionnaire.

	Poor	Fair	Good	Excellent	*n*	*M*	*SD*
Own major understanding	2 (5%)	4 (10%)	20 (51%)	13 (33%)	39	3.13	0.80
Others' understanding of your major	15 (38%)	16 (40%)	8 (20%)	1 (3%)	40	1.88	0.82
Interdisciplinary knowledge	6 (15%)	18 (45%)	12 (30%)	4 (10%)	40	2.35	0.86
Collaboration abilities	1 (3%)	3 (8%)	27 (68%)	9 (23%)	40	3.10	0.63
	Not motivated	Somewhat motivated	Motivated	Very motivated			
Motivation to collaborate	6 (16%)	3 (8%)	21 (55%)	8 (21%)	38	2.82	0.95
Motivation to do well	1 (3%)	1 (3%)	12 (30%)	26 (65%)	40	3.58	0.68

5.2. Disciplinary and Professional Conceptions

In the initial reflection, we identified misconceptions regarding the nature of each major based on the responses provided. Specifically, we found that 17% of engineering responses, 33% of communications responses, and 2% of business responses demonstrated misconceptions about their respective fields. In the case of engineering, the misconceptions primarily revolved around oversimplifying the role of engineers, with responses such as, "They engineer products with electrical components" or "Math, building things." On the other hand, misconceptions related to communications often involved confusion regarding professional roles, as seen in responses like "...create and deliver creative advertising and marketing strategy" or "They will market better and be able to reach out and talk to more people about our project."

As the reflections progressed and students engaged further in the project, we observed notable changes in how they perceived other majors. In fact, by the third reflection, a significant 58% of students reported a shift in their conceptualization of other majors. This transformation was evident through recurring statements such as, "It has made me have a newfound respect for the skills that each member of my team possesses" and "Before, I was a little confused about the difference between communication and marketing. I think I have a better understanding now". In addition to changing conceptions, we also found students evolved in their understanding of the professional roles one another might take in the future. At the beginning, we found that students tended to view disciplines and their groupmates from other majors as instrumental for the course project, rather than a focus on what they will be doing in their careers. For instance, one student commented on the question about what engineering majors do, "I would guess the electrical engineer designs the hardware side of the kites, and the software engineer designs the computer side." By the end of the project, we saw a clear increase in statements from students that extended work on the project to the professional world. One student's comment on their 'letter to me' captures this transformation:

> "Get ready to be challenged as a professional with your SOAR project. You are going to have to step out of your role as a student and become a professional communicator. You are not alone in wanting your project to be successful."

5.3. Interdisciplinary Orientations

Initiating the SOAR project was a challenge for many students, and each came with a diverse set of disciplinary understandings and preconceptions about what the project would entail. At the beginning of the project and extending through the mid-point, most students delineated disciplinary roles for one another—using phrases to describe group roles like, "...in charge of...", "...responsible for....", "...expected to...." While this may be a natural product of the nature of work (i.e., an engineering project brought to market), we found that on each successive reflection, fewer students kept a primarily disciplinary focus, with more students adapting interdisciplinary orientations to the project over time (Table 4). The focus slowly shifted from specific responsibilities of individuals to group responsibilities and processes.

Table 4. Group proportions for interdisciplinary learning orientations.

	Reflection 1 (*n* = 42)	**Reflection 2 (*n* = 37)**	**Reflection 3 (*n* = 36)**	**Reflection 4 (*n* = 37)**	**Reflection 5 (*n* = 38)**
Disciplinary orientation	36 (86%)	30 (81%)	28 (78%)	26 (68%)	14 (39%)
Interdisciplinary orientation	5 (14%)	7 (19%)	8 (22%)	11 (32%)	24 (63%)

Progressive reflections co-occurred with team experiences and challenges. We observed that challenges, particularly for groups that were well-prepared, boosted team morale and perceived authenticity of the work. By the final reflection, 'letter to me', we observed extensive gratitude and fondness for one another's contributions. For example:

> "There will be some challenges you have no control over, but it is vital to maintain discipline among yourself and help your team members if they are falling behind. The keyword in this project is teamwork."

> "One thing I really loved about SOAR was the ability to work with students from other majors. Not only was I able to meet new people, but I learned a lot about engineering and business that I otherwise would not learn."

However, for many students, this cohesive interdisciplinary collaboration remained lacking. We observed that some students maintained a focus on their own disciplinary skillset for collaboration, had a disposition of self-reliance, and/or deficit perspectives of their peers. For some of these students, they may perceive their collaborators as less able than themselves. For example, the following student comment to themselves in the 'letter to me' occurring at the end of the project:

> "I know you will let the business and communication students edit your work because you think they can write better, but you will see that is not the case. You and the other engineering students can do much better job than they are, because you care about this project much more and you understand it better. . ."

This comment, and others, represent more than just a disciplinary orientation—extending to personal characteristics and a more general dynamic that may have been occurring within groups with diverse individuals (e.g., lacking contributions from all, conflict, predispositions).

5.4. Cooperative Learning Orientations

Upon analyzing the data, we identified notable increases in all five cooperative learning orientations over time, although the change was not consistently linear when examined collectively. During the initial survey, we observed some evidence of positive interdependence, individual accountability, and limited indications of promotive interaction among the participants. Following a team-building activity conducted during the third reflection, we detected significant improvements in positive interdependence, promotive interaction, group processing, and social skills. By the time of the final reflection, coinciding with the submission of the final group work, we witnessed substantial and demonstrable increases in all cooperative learning orientations. These trends indicate a clear pattern of enhanced cooperation resulting from continuous engagement in interdisciplinary group projects (for descriptive statistics, refer to Table 5, and for a visual representation of the cooperative learning orientations over time, consult Figure 2).

Table 5. Descriptive statistics for cooperative orientations.

	Reflection 1 (*n* = 42)		**Reflection 2 (*n* = 37)**		**Reflection 3 (*n* = 36)**		**Reflection 4 (*n* = 37)**		**Reflection 5 (*n* = 38)**	
	M	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***
Positive interdependence	1.00	0.00	0.95	0.74	1.11	0.71	0.95	0.81	1.50	0.76
Individual accountability	1.02	0.47	1.35	0.72	1.13	0.91	0.97	0.87	1.53	0.73
Promotive interaction	0.52	0.67	0.51	0.77	0.97	0.83	0.97	0.87	1.50	0.76
Group Processing	N/A	N/A	0.73	0.73	0.88	0.77	0.86	0.89	1.45	0.76
Social skills	N/A	N/A	0.46	0.77	0.91	0.75	0.70	0.81	1.42	0.83

Note: Scale is 0 = NA; 1 = Some Evidence, 2 Extensive Evidence.

> "Open yourself up earlier so you can understand everything you can about this amazing product you have the honor of working on with some awesome engineers and don't be afraid to ask questions."

> "Everything will work out great when you address assumptions and have the chance to talk about things in person."

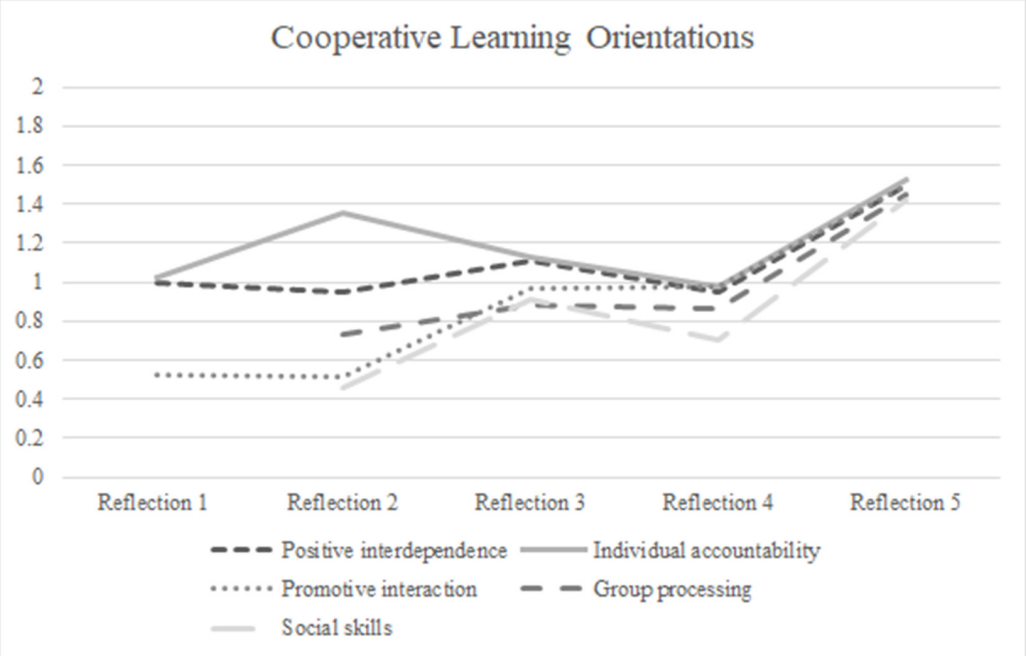


Figure 2. Cooperative learning orientations. Note: DV is the mean value of cooperative learning orientation: Scale is 0 = N/A, 1 = some evidence, 2 = extensive evidence.

During the final reflection, we assessed the orientations of students towards their groups and the project (Table 6). At the beginning of the semester, when asked about their initial experiences working in groups, about a half of students (48%) expressed negative predispositions. However, by the end of the semester, only one student reported negative feelings about their group. This significant shift in disposition toward group work is evident in the following comment provided by a student:

Table 6. Proportions of emotions characterizing the pre- and post-dispositions.

	Predispositions	Post-Dispositions
Positive	4 (11%)	28 (74%)
Negative	18 (47%)	1 (3%)
Neutral	10 (26%)	1 (3%)
Mixed	2 (5%)	8 (21%)
Nervous	4 (11%)	0 (0%)

Note: $n = 38$.

> "In my previous group projects, most. . . barely contributed to the final product. I used to be one of these students. . . I really decided to crack down and contribute to the group."

At the end of the project, more than a half of students (about 74%) reported enthusiastically positive feelings about their groups. We found that as most students reflected on the experience holistically, they were able to see the many actions taken and not taken that affected the process and recognize that they could not have succeeded alone. For example, one student commented:

> "You will find this experience extremely rewarding and you should make the effort to experience all aspects of the process. The multi-discipline aspects of this project amplify this even more. . ."

> "Your passive behavior in the group will lead to an unsuccessful project. Only finishing your own portion is not enough to succeed."

5.5. Mindset

On the final reflection, from the 'letter to me', we were able to gain a more rounded window into student thinking and to establish, with confidence, whether they had adopted a primarily fixed vs. growth orientation toward learning about other disciplines and skills for their future endeavors. The letters provided evidence that 84% of students exhibited a growth mindset, evidencing students overcoming their aversion to risk or discomfort and encouraging themselves to take on new challenges. Comments from students often are hedged with a desire to have embraced a more growth- and open-minded perspective earlier, for example:

> "Congratulations!! You just won the ticket to be a part of a group that is filled by some extraordinary, talented, and kind people. So, you! Pretentious, judgmental, despicably self-involved wanker better fight with every fiber of your being to put yourself out there and truly be a part of this amazing group of young people right at the beginning."

However, we identified a subset of students who exhibited a fixed mindset (16%) and a grade-focused orientation toward the course (13%), rather than prioritizing the project goals. One student's final comment exemplified this perspective: "You don't really need me to tell you what to do to be successful in this class because you already know." We recognize that these comments may also reflect preexisting biases that were reinforced by the behaviors of group members and individual experiences.

5.6. Educational Progression

In the 'letter to me', each student provided insights into their approach to the project at the beginning. Students (58%) openly expressed their confusion or difficulties during the initial stages of the project. The students overwhelmingly recommended embracing an open-minded growth mindset and shared instances during the project that altered their perspectives. For example, regarding the initial challenge at the project's onset, one student remarked: "During this semester, you'll be faced with a project proposal for this course that seems very difficult and damn near impossible at first, but it won't be."

Other students commented about past behaviors and encouraged themselves to make a transformation sooner. For instance:

> "Throughout this semester, I found multiple solutions for my time management problems. Most of the time if you communicate with your superiors whether at work or at school, they will help you come up with a solution. Don't be afraid to tell others about your problems: Most of the time people will help you."

Finally, students commented on how crucial communication was to engage in the project and build group cohesion. One student wrote this to their past self:

> "I think the biggest thing I could tell you, is that you will need to communicate with your groupmates and teacher a lot more. When things get confusing, and you don't know where to go or where to look, that is the perfect time to ask for some help."

6. Significance and Implications

Across the United States, teacher-centered instruction in undergraduate classrooms remains common and assessments remain one-off high-stakes tests used for accountability and marking purposes. This is despite longstanding research that demonstrates students learn better through active, student-centered, and collaborative learning environments [13,25]. Guided by a theory of action for interdisciplinary project-based learning, most students were engaged in the SOAR project and experienced enhanced outcomes in learning, cooperation, mindset, and interdisciplinary understanding.

Our study revealed that implementing an interdisciplinary group project for students from various majors posed challenges, yet it proved to be a rewarding experience for

both students and instructors. Although students initially faced confusion and difficulties, along with some misconceptions about their peers' majors, there was ample evidence of improved interdisciplinary understanding, group dynamics, satisfaction, and mutual appreciation as the project progressed. In line with research on project-based cooperative learning and formative assessment, the structure of the project and groups was essential to realizing these outcomes. Notably, by embedding a formative assessment process within the project, we enabled students to iteratively apply clear criteria for success to both group and individual work. It also provided opportunities for frequent low-stakes critique via the provision of peer and instructor feedback on checkpoints, and structured opportunities for self-reflection [17,36].

By offering students a template for the project that was broken down by deliverables, we enabled students to set their own goals, roles, and timelines for the project. This scaffolded a shared understanding of the work of each discipline and the purposes of the SOAR project. We believe this all contributed to students' positive interdependence, promotive interaction, individual accountability, interpersonal social skills, and group processing as shown in Table 5 and Figure 2—in line with the work of [13,29]. The observed trend across student reflections implies that students tended to focus more on individual accountability before later adopting other facets of cooperative learning such as promotive interaction and social skills. Further, we found evidence that cooperative work among students of different disciplines led to many developing a sense of trust and confidence [23].

The results of our analysis of students' 'letter to me' also indicate the project cultivated a growth mindset in students by breaking down disciplinary silos and misconceptions among students of different majors. The structured collaborative opportunities afforded by the SOAR project appears to have enabled students to see their work improving with each iteration and embrace the diverse contributions of their groupmates, which is consistent with the findings of [33]. We also found corroborative evidence for the beliefs about intelligence and learning were associated with students' academic experiences, observations of peers, social cues, and formal learning opportunities. Further, we found SOAR projects influenced students' interests in STEM, perceptions of their own skillsets, and the utility of the course [26]. We believe this is particularly due to the authenticity of the project to the professional world and real-world outputs that students generated [37]. Upon completion of the more summative aspects of the project (i.e., the product pitch to stakeholders), it is clear most students took considerable pride in their work, had gratitude for their peers' contributions, and experienced significant learning that could be continued into their careers.

Limitations

This study has several limitations that bound our interpretation and opened avenues for further research. Our study is a description of one semester implementing and examining the outcomes of the SOAR project at one university campus and is not representative of other contexts. Further, we were only able to collect information anonymously and we were not able to link data to the same students over time—limiting inferences that can be made at the individual level. We acknowledge also that there were students who did not participate in all reflections. The scope of our study is, therefore, bound by these factors and should be interpreted as such. Another limitation is the lack of statistical analyses due to the small sample size. Hence, a more robust study with statistical analyses, or longitudinal and larger-scale research, is needed to confirm our findings across contexts.

7. Conclusions

The present study underscores the power and potential of interdisciplinary project-based approaches, so-called SOAR, in fostering deeper collaboration and cultivating essential academic and workplace skills among future professionals. It highlights the significant role of such approaches in promoting interdisciplinary learning, teamwork, and the development of valuable competencies sought after in professional settings. Bringing together

electrical engineering, communications, and marketing educators and students to work on industry-sponsored projects with real-world implications led to increased authenticity, collaboration, and achievement in the work and products of groups. This approach also led to a transformation in the learning orientations of students who shifted from the view of themselves as students to professionals capable of more than they originally envisioned. Further research is needed to explore how facets of interdisciplinary projects and teams affect motivation, mindset, collaboration, and the ultimate quality of products.

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