

EmPOWERing a Sustainable Energy Future through Interconnected Curricular and Co-Curricular Pedagogies

Prof. Jeffrey M. Bielicki, The Ohio State University

Dr. Bielicki is the Program Director and Principal Investigator of the OSU EmPOWERment Program on convergent graduate training for a sustainable energy future. He is also research lead for Sustainable Energy for the OSU Sustainability Institute and he runs the Energy Sustainability Research Laboratory where he and his students research issues in which energy and environmental systems and policy interact, specifically on topics related to carbon management, renewable energy, and the energy-water nexus.

Yun-Han Weng, The Ohio State University

Emily T Creamer, The Ohio State University

Matthew Judkins Mayhew, The Ohio State University

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Abstract

In 2019, a National Research Traineeship (NRT) grant from the U.S. National Science Foundation seeded the establishment of a new model for graduate education at Ohio State University – a large, public, land-grant R-1 university in the U.S. Midwest. This grant application involved faculty from eight different colleges within this university (education; engineering; public affairs; arts and sciences; food, agriculture, and environmental sciences; business; law). The *Ohio State EmPOWERment Program* in convergent graduate training for a sustainable energy future enrolls Ph.D. students studying any aspect of energy from degree programs any college in Ohio State and engages them in several curricular and co-curricular elements that are designed to dovetail with their Ph.D. degree program requirements in ways that do not extend their time to graduate. The *Ohio State EmPOWERment Program* established at Ohio State an energy Student Community of Practice and Engagement (SCOPE), a Graduate Interdisciplinary Specialization (GIS), and an undergraduate Research in Sustainable Energy (RISE) summer research experience. Over time a JOULE energy seminar series (JOULE) was added to elevate intellectual engagement in for trainees in The *Ohio State EmPOWERment Program* and broaden their engagement with researchers across this university. This paper investigates the development and accentuation of innovation capacities of Ph.D. trainees in *The Ohio State EmPOWERment Program* relative to other Ph.D. students who enrolled in science, technology, engineering, and math (STEM) disciplines at Ohio State and did not participate in the *Ohio State EmPOWERment Program*. This work considers three different constructs for each of three scales (i.e., Interpersonal, Intrapersonal, Cognitive). Of the nine different constructs, six pass assumption tests and *pre-test scores* for *innovation self-concept*, *proactivity*, *social networking*, *risk-taking or tolerance*, *creative capacity*, and *intention to innovate* are significant predictors of *post-test capacities*. Overall, participating in The *Ohio State EmPOWERment Program* appears to be beneficial and may increase *innovation self-concept*, *proactivity*, *creative*, and *intention to innovate* capacities.

1 Introduction

The higher educational landscape in the United States must prepare graduates to address grand challenges facing the country and the world. Several lists of these challenges have been generated by different entities such as the U.S. National Academy of Engineering and the U.S. Agency for International Development, some of which are specific to particular fields like Environmental Engineering [1]. This emphasis has prompted a significant expansion in STEM disciplines to encompass a spectrum of complex scientific pursuits that demand a concerted and interdisciplinary methodology. In response, the U.S. National Science Foundation developed several funding opportunities (e.g., Innovations in Graduate Education (IGE), National Research Traineeship (NRT)) to collaborate with institutions of higher education to develop comprehensive interdisciplinary STEM graduate training programs. These programs are designed to endow aspiring scientists with a diverse skill set crucial for addressing the formidable challenges our society confronts [2], [3]. The transition to a more collaborative and team-oriented research ethos is also evidenced by the increase in multi-authored peer-reviewed publications and a profound transformation in the traditional structure of university knowledge ecosystems. Ph.D. students in STEM fields are central to this educational and research evolution. These Ph.D. students are indispensable to the continuum of STEM innovation as they have pivotal roles in the genesis and propagation of new knowledge [4]. Nonetheless, a substantial number of these emerging scholars are sequestered within the confines of conventional, single-discipline academic programs. Such programs may not provide exposure to and opportunities to participate in the kinds of interdisciplinarity documented as indispensable for the development of innovative solutions in energy sustainability. The scarcity of comprehensive interdisciplinary training and mentorship can significantly hinder the potential of these students to nurture their innovative capacities, forge resilient interdisciplinary identities, and foster the self-efficacies that are essential for flourishing in multifaceted scientific domains. Given that the structure of modern universities continues to be organized around disciplinary pursuits, there are opportunities to develop and implement interdisciplinary training programs that work with the depth of existing Ph.D. degree programs while spanning across them to provide the interdisciplinary exposure and breadth to address grand challenges.

Previous research in interdisciplinary STEM education has revealed challenges and opportunities faced by graduate students and higher education institutions in navigating interdisciplinary research and teaching landscapes. Key themes include but are not limited to: the cultivation of a community-oriented team culture to enhance scientific team cohesion and productivity e.g., [5]; the importance of academic motivation and teamwork diversity in interdisciplinary context [6]; the mechanisms that facilitate team science e.g., [7], and the perspectives of graduate students and early career academics on interdisciplinary research e.g., [8]. These studies collectively underscore the complexity of interdisciplinary endeavors, and highlight the need for supportive institutional structures, the development of interdisciplinary communication and collaboration skills, and the strategic navigation of career paths that balance disciplinary and interdisciplinary commitments. The literature suggests a growing recognition of the value of interdisciplinary approaches in addressing complex problems and points to significant institutional and cultural barriers that must be overcome to foster effective interdisciplinary collaboration and training.

Selznick and Mayhew [9] defined *innovative capacities* as a set of self-perceptions, skills,

and abilities that individuals can acquire to actively engage in the innovation process. Contrary to the belief that innovation cannot be developed, their framework posits that certain aspects of innovation are teachable and can be learned. The framework emphasizes the role of students, who, through involvement in the formal college curriculum and extracurricular activities, can nurture and apply these innovation capacities. This perspective underscores the importance of demographic and educational factors that may influence the development of these capacities. Several studies have investigated collegiate mechanisms or individual characteristics that may develop innovation capacities in undergraduate students. Key factors include engagement in innovation-related coursework [10] and positive interactions with faculty [11]. Yet there is a notable emphasis on the importance of educational practices that are inclusive and consider student identities and academic majors [12], [13]. These studies highlight the crucial role of higher education in fostering innovation among students, with a particular focus on equitable access to innovation-enhancing opportunities [14].

Building on the existing research in interdisciplinary STEM education and the foundational work of innovation capacities, there is a clear need for the intentional integration of innovative capacity-building within graduate STEM programs and the translation of theoretical knowledge into tangible outcomes. Doing so entails a deeper exploration into how interdisciplinary curricula translate into practical skills that can address real-world issues. By aligning educational strategies with the demands of contemporary research and development sectors, Ph.D. students may be better prepared to contribute to and lead in the evolving landscape to address grand challenges. In these contexts, the *Ohio State EmPOWERment Program* was established at Ohio State University – a large, public, land-grant R-1 university in the U.S. Midwest – and we seek to understand the degree to which engagement in the *Ohio State EmPOWERment Program* accentuates the innovation capacities among first-year Ph.D. student trainees in the *Ohio State EmPOWERment Program*.

2 The goals and elements of The *Ohio State EmPOWERment Program*

The *Ohio State EmPOWERment Program* was established by a \$3M NRT grant by the U.S. National Science Foundation and is an interdisciplinary convergent training program designed to develop Ph.D. students who are experts in the design, application, and widespread adoption of sustainable, decarbonized energy systems. The goals of the *Ohio State EmPOWERment Program* were developed by twelve faculty in departments across six colleges within the university, in consultation with external stakeholders who work in industry, U.S. national laboratories, and non-profit organizations. These stakeholders are ensconced in various aspects of the field of sustainable energy. Together, this process identified important attitudes, experiences, and core competencies necessary to support three-overarching program goals:

1. Prepare a diverse cohort of versatile graduates with the innovation capacity, self-efficacy, and collaborative capacity to influence positive change in the transition to environmentally, economically, and socially benign energy systems;
2. Leverage and catalyze convergent research for sustainable energy solutions with energy sector partners, using the campus of the university as a testbed; and

3. Refine this new convergent traineeship model through continuous evaluation and disseminate replicable best practices and lessons learned.

The *Ohio State EmPOWERment Program* is in principle open to any Ph.D. student studying any aspect of energy in a Ph.D. program in any college within this university. The *Ohio State EmPOWERment Program* uses a cohort model where Ph.D. trainees pursue their Ph.D. degree in an established department while they participate in the *Ohio State EmPOWERment Program* – which has several distinctive elements that are summarized next.

2.1 Graduate Interdisciplinary Specialization (GIS)

A nineteen-credit Graduate Interdisciplinary Specialization (GIS) was established, in which *EmPOWERment Trainees* and other graduate students take a common course in the foundations of sustainable energy systems (“foundations course”) at the beginning, and a course on innovating for sustainable energy (“capstone course”) at the end. Between these two courses, graduate students who fulfill the GS also take one course in four out of five thematic areas: (1) energy and environmental systems; (2) data analysis and information systems; (3) energy policy, regulation, behavior, and economics; (4) energy business modeling; and (5) energy technologies, components, and subsystems). The foundations course and the capstone course were developed specifically to establish the *Ohio State EmPOWERment Program*, whereas the course options in the thematic areas were drawn from existing courses at the university. The courses that fulfill the thematic areas were solicited from faculty at the university and parsed among the thematic areas, and a petition process was established for students to add courses to, or substitute courses for, approved courses in the GIS. The GIS is designed to dovetail with Ph.D. degree program requirements across this university and not extend the time to graduate.

2.2 Energy Student Community of Practice and Engagement (SCOPE) and JOULE Energy Seminar Series (JOULE)

In partnership with a center at the university that focuses on workforce development at the intersection of science, engineering, and public policy, a bi-weekly energy Student Community of Practice and Engagement (energy SCOPE) was established. In the SCOPE, *EmPOWERment Trainees* and other graduate students partake in skills-building workshops and interact with people from industry, non-profits, and government agencies on energy and sustainability issues that are pertinent to the institution and the energy transition.

A university-wide JOULE Energy Seminar Series (JOULE) was established a few years into the *Ohio State EmPOWERment Program* to promote the intellectual academic engagement with various avenues of inquiry in energy. This provides a forum for trainees, faculty, and research staff at the university, as well as researchers external to the university, to present their scholarly work in a supportive and conversant atmosphere. By focusing on the intellectual engagement, JOULE complements the energy SCOPE and its focus on skills building and career engagement.

2.3 Undergraduate Research in Sustainable Energy (RISE) Summer Experience

The Undergraduate Research in Sustainable Energy (RISE) Summer Experience is ten-week research experience for undergraduate students that prioritizes students from underrepresented communities and seeks to diversify the population of graduate students by engaging them prior to their senior year, providing them with a semi-independent research experience in energy and sustainability, and providing them with programming that is tailored to their backgrounds and levels them up with insight into processes to successfully apply and be admitted to graduate school. While this element of the *Ohio State EmPOWERment Program* is not targeted to the Ph.D. trainees in the *Ohio State EmPOWERment Program*, these trainees often serve as resources and speak to the undergraduate students in RISE.

2.4 Bootcamp

Incoming cohorts of trainees in the *Ohio State EmPOWERment Program* participate in a two-week level-setting bootcamp to get exposure to elementary data analytics in the context of a challenge problem from an external sponsor. Trainees in the cohort work on interdisciplinary teams to address the challenge problem, with presentations from faculty with expertise pertinent to the problem interspersed among the two weeks. Beginning in the second year, trainees in prior cohorts serve as mentors and resources for those in the new cohort.

2.5 Advisory committees

The *Ohio State EmPOWERment Program* has an Internal Advisory Committee (IAC) and an External Advisory Committee (EAC). The IAC provides strategic guidance for navigating within the university and in creating opportunities for the *Ohio State EmPOWERment Program*. In contrast, the EAC is composed of representatives from several external entities in the energy sector (e.g., industry, national laboratories, non-profits). Members of the EAC were instrumental in helping to establish the educational learning outcomes underlying the GIS and provide external guidance and engagement for navigating various career paths (e.g., consulting, academia, industry) for trainees who complete the *Ohio State EmPOWERment Program*.

2.6 External Engagement (EE)

In addition to the EAC, there are several ways in which trainees in the *Ohio State EmPOWERment Program* engage with people who are external to the university and ensconced in the landscape of the energy sector. For example, in addition to the bi-weekly SCOPE and the Bootcamp, each trainee in the *Ohio State EmPOWERment Program* has an external mentor. This external member can be drawn from one of the entities that engages with the SCOPE or is a member of the EAC, but they do not have to have another mode of engagement with the *Ohio State EmPOWERment Program* to be an external mentor.

2.7 Advising and Mentoring (A&M)

In addition to their primary Ph.D. advisor, and their external mentor, each trainee in the *Ohio State EmPOWERment Program* has another mentor internal to the university. This internal mentor can be a faculty member or have a role in research, but they do not have to be involved with research or teaching at this university. This internal mentor can be a source of support to

the trainee as the trainee navigates their Ph.D. degree and their participation in the *Ohio State EmPOWERment Program*.

2.8 Individual Development Plan (IDP) and a Participation Agreement (PA)

Each trainee in the *Ohio State EmPOWERment Program* completes an Individual Development Plan (IDP) and a Participation Agreement (PA) at the beginning of their participation in the *Ohio State EmPOWERment Program*. The PA outlines the expectations for participation in the *Ohio State EmPOWERment Program*, and the IDP is updated annually. The PA is signed by the Ph.D. trainee and their Ph.D. advisor.

3 Conceptual framework for evaluation of The *Ohio State EmPOWERment Program*

To address our research questions, this study adopted a constructive-developmental perspective of adult psychological and epistemological growth to understand individual aspects of innovation [15], [16], [17]. Drawing on the foundational work of Piaget (1985), Erikson (1956), Kohlberg (1958) and others, Kegan's framework identifies several developmental moments adults encounter when certain events and information trigger dissonance and/or psychological imbalance. This progression is facilitated by a process of restructuring, leading to the formation of more intricate and nuanced psychological structures able to reconcile the discomfort certain developmental encounters – or educational experiences - engender. Concurrently, it involves the gradual transformation of one's sense of self, shifting from being influenced by various factors such as impulses, desires, experiential categories, social systems, and self-conceptions, to a state where these factors become objects that can be examined and manipulated.

Kegan (2018) delves into three fundamental dimensions of development where individuals encounter discomfort: the cognitive, intrapersonal, and interpersonal. The cognitive dimension pertains to an individual's increasing ability to effectively process and comprehend information. Simultaneously, the intrapersonal dimension focuses on self-awareness, self-reflection, and the regulation of emotions and thoughts. Lastly, the interpersonal dimension involves an individual's capacity to engage in and comprehend relationships with others, though the process of developing empathy and co-creating shared meaning. These dimensions represent distinct modes of development and influence how individuals perceive and interact with the world, themselves, and others. Following this framework, our study uses Kegan's theory to position developmental ideas associated with innovation and inform understandings of relationships between educational environments and outcomes.

4 Methodology

The data used in this work is part of a larger dataset for longitudinal research on the outcomes of the *Ohio State EmPOWERment Program*. In this section, we provide an overview of the sample, study design, measures, and analyses utilized to evaluate the role that the *Ohio State EmPOWERment Program* has in fostering capacities for innovation among trainees. This section concludes with a brief review of limitations.

4.1 Sample and study design

To facilitate an effective comparative analysis, the design of this study involves an experimental group drawn from Ph.D. Trainees in the *Ohio State EmPOWERment Program* and a broader control group of Ph.D. students who are not in the *Ohio State EmPOWERment Program*. The experimental group population consists of 24 Ph.D. Trainees from the *Ohio State EmPOWERment Program*, of whom fifteen consented and completed the entire research process for this study. The control group population is composed of all other first-year Ph.D. students enrolled at the same university but not participating in the *Ohio State EmPOWERment Program*. From this population, 105 students completed the entire research process. The rationale underlying the selection of these specific groups was to compare the effects of the experiences in the *Ohio State EmPOWERment Program* (experimental group) with the general experience of first-year Ph.D. students elsewhere in the university (control group). This approach allows us to isolate and evaluate the unique contributions of the *Ohio State EmPOWERment Program* to innovation capacities.

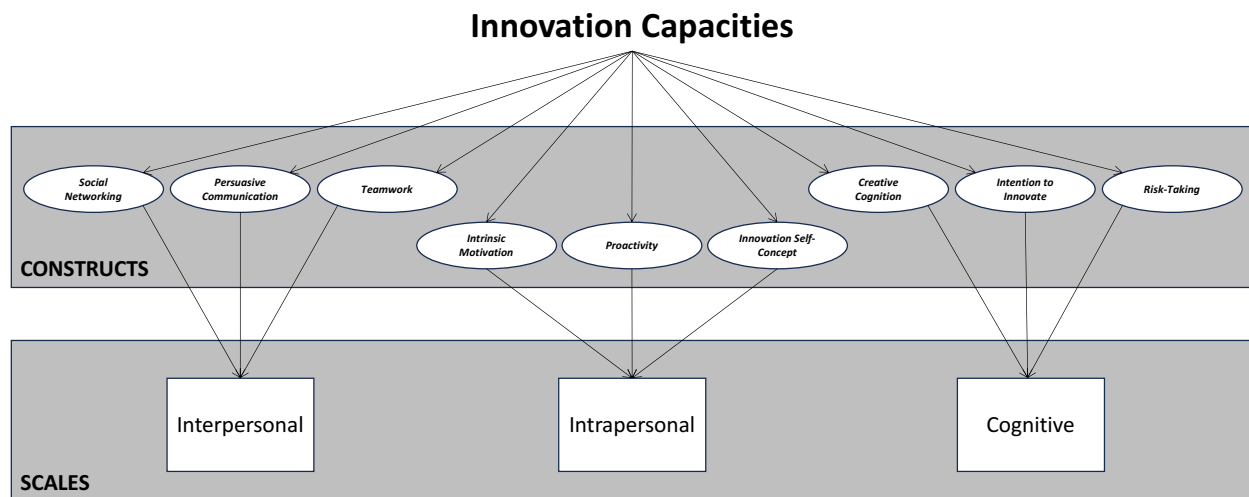


Figure 1: Framework for Evaluation of Innovation Capacities for Trainees in The *Ohio State EmPOWERment Program*.

4.2 Measures

The primary measure used here is a theoretically supported, reliable, and valid instrument designed to assess the innovation capacities of students [9]. The innovation capacities scores are second-order factor scores calculated from nine conditioned constructs: three for interpersonal (*networking, persuasive communication, teamwork across difference*), three for intrapersonal (*intrinsic motivation, proactivity, innovation self-concept*), and three for cognitive (*creative cognition, intention to innovate, and risk taking/tolerance*) scales. Instead of using a second-order model to assess the innovation capacities of students, we implement a repeated sequential regression approach so that we can investigate in detail the individual contributions of the nine

constructs. By using the repeated sequential regressions, we investigate the influence of each of the constructs independently and provide a nuanced understanding of their distinct roles in fostering innovation capacities. Figure 1 shows the constructs and the scales that they comprise.

The Intrapersonal Scale assesses an individual's self-awareness, self-perceptions, and capabilities in fostering creative ideation and execution in the context of innovation and entrepreneurship. This measure encompasses constructs including *intrinsic motivation*, *proactivity*, and *innovation self-concept*. The *intrinsic motivation* construct measures an individual's level of motivation to engage in innovative and entrepreneurial activities. The *proactivity* construct examines an individual's tendency to take initiative and be proactive in pursuing their goals. The *innovation self-concept* construct tests individuals in performing specific tasks related to innovation and entrepreneurship, such as generating new ideas or identifying opportunities.

The Interpersonal Scale pertains to the measurement of social aspects and interactions that influence innovation and entrepreneurship among students in higher education. It includes constructs such as *social networking*, *persuasive communication*, and *teamwork across differences*. These constructs reflect students' perceptions of the social domain and their ability to engage in social experiences that support innovation and career development within the higher education environment. *Networking* measures an individual's ease in establishing and maintaining mutually advantageous new connections. *Persuasive communication* assesses the perceived effectiveness of one's capacity to convey new ideas and action plans clearly to others. *Teamwork across differences* gauges the perceived effectiveness of one's ability to collaborate within a group comprising diverse individuals to accomplish a shared objective.

The Cognitive Scale refers to the measurement of cognitive abilities and processes associated with innovation and entrepreneurship. It includes constructs such as *creative cognition*, *intention to innovate*, and *risk-taking or tolerance*. These constructs reflect the cognitive dimensions that are essential for generating novel ideas, bridging gaps between knowledge domains, and functioning effectively in scenarios where new opportunities present themselves. *Creative cognition* assesses consensus on the pleasure derived from and the capability to engage in generating contextually advantageous novel concepts. *Intention to innovate* gauges the perceived effectiveness in recognizing new prospects, devising a strategy, securing resources, and establishing new entities. *Risk-taking or tolerance* evaluates one's self-assuredness in taking intellectual risks and showcasing divergent thinking within both academic and extracurricular settings.

4.3 Analysis

We implement a repeated sequential multiple linear regression to investigate how participation in the *Ohio State EmPOWERment Program* accentuates the development of innovation capacities among first-year Ph.D. students in STEM disciplines. For each construct, the dependent variable is the *post-test innovation capacities* for a construct, while the control

variable to account for the baseline of a student is *pre-test innovation capacities* for a construct. That is, the *pre-test innovation capacity* score for a construct is evaluated as a student enters the first year of their Ph.D. program, and the *post-test innovation capacity* score for a construct is evaluated one-year later as the student begins their second year in the Ph.D. program. The Innovation Self-Capacity Model in Eq. 1 is the base model for the regression performed on each of the nine constructs.

Model 1: Innovation Self-Capacity Model

$$Y = \alpha + \beta_1 X_1 \quad (\text{Eq. 1}),$$

where Y and X_1 are respectively the *post-test* and *pre-test* innovation capacity scores for the measure being investigated.

For a second model, we add a binary variable to the Innovation Self-Capacity Model to represent participation in the *Ohio State EmPOWERment Program*. This Group Participation Model allows us to differentiate results between those in the broader population of Ph.D. students at this university and those who participate in the *Ohio State EmPOWERment Program*.

Model 2: Group Participation Model

$$Y = \alpha + \beta_1 X_1 + \beta_2 X_2 \quad (\text{Eq. 2}),$$

where Y and X_1 are defined as in the Innovation Self-Capacity Model, and X_2 is the binary independent variable for participation in the experimental group. This variable, X_2 , is coded as 0 for the control group and 1 for the experimental group (i.e., trainee in the *Ohio State EmPOWERment Program*).

In a third model, the Interaction Model, we add an independent variable that is an interaction between the students' *pre-test innovation capacities* and *participation group*. This interaction variable, X_3 , facilitates the investigation of whether the impact of the *Ohio State EmPOWERment Program* on innovation capacities varies depending on students' initial capacities and whether the interaction between pre-test scores and group plays a significant role in shaping the outcomes of the program. This approach allows us to investigate potential moderation effects and gain a deeper understanding of the program's effectiveness in different contexts.

Model 3: Interaction Model

$$Y = \alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 \quad (\text{Eq. 3}),$$

where Y , X_1 , and X_2 are defined as in the Group Participation Model, and X_3 is the interaction term for X_1 and X_2 (i.e., $X_3 = X_1 X_2$).

5 Results

In the following subsections, we report the results for each construct that passed the assumption tests that are required for valid sequential linear regression analyses. In particular, the constructs that satisfy evaluations of linearity, homoscedasticity, absence of multicollinearity, and normality of residuals are: *innovation self-concept*, *proactivity*, *networking*, *risk-taking or tolerance*, *creativity*, and *intention to innovate*. The results articulated below, in Table 1 (summary statistics), and in Table 2 (regression results for individual innovation capacities), suggest that several capacities are significant predictors of innovation capacities among first-year Ph.D. students.

5.1 Interpersonal Scale

5.1.1 Social Networking Capacity

The consideration of *social networking capacity* in the Innovation Self Capacity Model significantly predicts *post-test scores* at the 0.1% level (Table 2: $\beta_1 = 0.796$, $p < 0.001$) and explained a substantial portion of the variance (Table 1: $R^2 = 0.633$). In the Group Participation Model, *pre-test scores* remains statistically significant at the 0.1% level (Table 2: $\beta_1 = 0.794$, $p < 0.001$) with an R^2_{change} of 0.011 (Table 1), but *group participation* is not statistically significant at the 5% level (Table 2: $\beta_2 = 0.330$, $p = 0.056$). In the Interaction Model ($R^2_{change} = 0.001$, Table 1), *pre-test scores* remains statistically significant at the 0.1% level (Table 2: $\beta_1 = 0.804$, $p < 0.001$) and *group participation* is statistically significant at the 5% level (Table 2: $\beta_2 = 0.336$, $p = 0.056$), yet the interaction between *pre-test scores* and *group participation* is not statistically significant (Table 2: $\beta_3 = -0.110$, $p = 0.563$).

5.2 Intrapersonal Scale

5.2.1 Innovation Self-Concept Capacity

The Innovation Self-Capacity Model explains 36.3% of the variance in *post-test scores* for *innovation self-concept capacity* (Table 1: $R^2 = 0.363$), and the centered *pre-test score* is statistically significant at the 0.1% level: $\beta_1 = 0.629$, $p < 0.001$ (Table 2). In the Group Participation Model, the R^2_{change} is 0.006 (Table 1), *post-test scores* for *innovation self-concept capacity* remain statistically significant 0.1% level: $\beta_1 = 0.603$, $p < 0.001$ (Table 2) and *group participation* is statistically significant at the 5% level (Table 2: $\beta_2 = 0.324$, $p = 0.016$). In the Interaction Model, there is no improvement in the amount of variance in *post-test scores* that are explained by the model ($R^2_{change} = 0$, Table 1), while the *pre-test scores* for *innovation self-concept capacity* remain statistically significant at the 0.1% level (Table 2: $\beta_1 = 0.599$, $p < 0.001$) and *group participation* is statistically significant at the 5% level (Table 2: $\beta_2 = 0.324$, $p = 0.016$), whereas the interaction between *pre-test scores* for *innovation self-concept capacity* and *group participation* is not statistically significant at the 5% level (Table 2: $\beta_3 = 0.030$, $p = 0.895$).

5.2.2 Proactivity Capacity

The Innovation Self Capacity Model explains 26.2% of the variance in *post-test scores* of *proactivity capacity* (Table 1: $R^2 = 0.262$), with *pre-test scores* of *proactivity capacity* significantly predicting *post-test scores* of *proactivity capacity* at the 0.1% level (Table 2: $\beta_1 =$

0.517, $p < 0.001$). The R^2_{change} with the Group Participation Model is 0.038 (Table 1) and *pre-test scores of proactivity capacity* remain statistically significant at the 0.1% level (Table 2: $\beta_1 = 0.499$, $p < 0.001$) and *group participation* is statistically significant at the 5% level (Table 2: $\beta_2 = .350$, $p = .011$). The interaction term in the Interaction Model ($R^2_{change} = 0$) is not statistically significant, while *pre-test scores of proactivity capacity* (Table 2: $\beta_1 = 0.505$) and *group participation* (Table 2: $\beta_2 = .358$) remain statistically significant at the same level as in the Group Participation Model.

5.3 Cognitive Scale

5.3.1 Risk-Taking or Tolerance Capacity

With *risk-taking or tolerance capacity*, the results in Table 2 show that *pre-test scores* are statistically significant at the 1% level across all of the models (Innovation Self-Capacity Model: $\beta_1 = .699$, $p < .001$; Group Participation Model: $\beta_1 = .693$, $p < .001$; Interaction Model: $\beta_1 = .665$, $p < .001$) with $R^2 = 0.471$ for the Innovation Self-Capacity Model and R^2_{change} from that model to the Group Participation Model of 0.006 and R^2_{change} from the Group Participation Model to the Interaction model of 0.009 (Table 1). In contrast, the results in Table 2 show that *group participation* is not statistically significant at the 5% level in either model that considers it (Group Participation Model: $\beta_2 = 0.209$, $p = 0.237$; Interaction Model: $\beta_2 = 0.349$, $p = 0.162$). Similarly, the interaction between *group participation* and *pre-test scores of risk-taking or tolerance* is not statistically significant at the 5% level.

5.3.2 Creative Cognition Capacity

With the *creativity capacity* construct, *pre-test scores* and *group participation* are significant at the 0.1% level in across all the models. For example, the results in Table 2 show that $\beta_1 = 0.572$ ($p < 0.001$) and $\beta_2 = 0.569$ ($p < 0.001$) in the Group Participation Model, and that $\beta_1 = 0.557$ ($p < 0.001$) and $\beta_2 = 0.532$ ($p < 0.001$) in the Interaction Model. The interaction term in the Interaction Model is not statistically significant at the 5% level ($\beta_3 = 0.126$, $p = 0.562$). There is a substantial increase in the amount of variance that is explained in the Group Participation Model relative to the Innovation Self-Capacity Model; the results in Table 1 show that $R^2 = 0.663$ for the Group Participation Model, which entails an $R^2_{change} = 0.291$, whereas $R^2_{change} = 0.002$ to the Interaction Model.

5.3.3 Intention to Innovate Capacity

Closely following the results for *creative cognition capacity*, the results in Table 2 show that the *pre-test scores for intention to innovate* and *group participation* are statistically significant at the 0.1% level in all the models, except that β_2 for *group participation* in the Group Model is statistically significant at the 1% level ($\beta_2 = 0.466$, $p = 0.010$) and in the Interaction model is statistically significant at the 5% level ($\beta_2 = 0.466$). Similarly, β_3 for the interaction term is not significant at the 5% level ($\beta_3 = 0.183$, $p = 0.467$).

Table 1: Results of the Sequential Linear Regression Model

Model	R^2	Adjusted R^2	R^2_{change}	Standard Error	F value	p value
<i>Social Networking Capacity</i>						
Innovation Self-Capacity Model	0.633	0.630	0.633	0.607	206.820	< 0.001
Group Participation Model	0.644	0.638	0.011	0.600	3.737	0.056
Interaction Model	0.645	0.636	0.001	0.602	0.337	0.563
<i>Innovation Self-Concept Capacity</i>						
Innovation Self-Capacity Model	0.363	0.358	0.363	0.487	69.036	< 0.001
Group Participation Model	0.393	0.383	0.030	0.477	5.948	0.016
Interaction Model	0.393	0.378	0.000	0.479	0.018	0.895
<i>Proactivity Capacity</i>						
Innovation Self-Capacity Model	0.262	0.256	0.262	0.504	42.979	< 0.001
Group Participation Model	0.301	0.289	0.038	0.493	6.590	0.011
Interaction Model	0.301	0.283	0.000	0.495	0.064	0.801
<i>Risk-Taking or Tolerance Capacity</i>						
Innovation Self-Capacity Model	0.471	0.466	0.471	0.620	106.673	< 0.001
Group Participation Model	0.477	0.468	0.006	0.619	1.411	0.237
Interaction Model	0.485	0.472	0.009	0.616	1.981	0.162
<i>Creative Cognition Capacity</i>						
Innovation Self-Capacity Model	0.372	0.367	0.372	0.556	71.716	< 0.001
Group Participation Model	0.663	0.431	0.291	0.527	14.598	< 0.001
Interaction Model	0.665	0.428	0.002	0.529	0.339	0.562
<i>Intention to Innovate Capacity</i>						
Innovation Self-Capacity Model	0.264	0.258	0.264	0.659	43.816	< 0.001
Group Participation Model	0.303	0.292	0.039	0.644	6.787	0.010
Interaction Model	0.306	0.306	0.003	0.645	0.5333	0.467

Table 2: Results of the Sequential Linear Regression for Post-Test Innovation Capacities

	Innovation Self-Capacity Model	Group Participation Model	Interaction Model
<i>Social Networking Capacity</i>			
α (constant)	3.424***	3.386***	3.386***
β_1 (centered pre-test score)	0.796***	0.794***	0.804***
β_2 (group participation)		0.330	0.336*
β_3 (centered pre-test score x group participation)			-0.110
<i>Innovation Self-Concept Capacity</i>			
α (constant)	3.994***	3.954***	3.954***
β_1 (centered pre-test score)	0.629***	0.603***	0.599***
β_2 (group participation)		0.324*	0.318*
β_3 (centered pre-test score x group participation)			0.030
<i>Proactivity Capacity</i>			
α (constant)	4.106***	4.063***	4.063***
β_1 (centered pre-test score)	0.517***	0.499***	0.505***
β_2 (group participation)		0.350*	0.358*
β_3 (centered pre-test score x group participation)			-0.068
<i>Risk-Taking or Tolerance Capacity</i>			
α (constant)	3.525***	3.501***	3.501***
β_1 (centered pre-test score)	0.699***	0.693***	0.665***
β_2 (group participation)		0.209	0.153
β_3 (centered pre-test score x group participation)			0.349
<i>Creative Cognition Capacity</i>			
α (constant)	3.867***	3.798***	3.798***
β_1 (centered pre-test score)	0.608***	0.572***	0.557***
β_2 (group participation)		0.560***	0.532***
β_3 (centered pre-test score x group participation)			0.126
<i>Intention to Innovate Capacity</i>			
α (constant)	3.587***	3.530***	3.529***
β_1 (centered pre-test score)	0.578***	0.548***	0.523***
β_2 (group participation)		0.466**	0.428*
β_3 (centered pre-test score x group participation)			0.183
N = 124. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$			

6 Discussion and Conclusions

While this study has some limitations – namely (1) the one-year duration between pre-test and post-test assessments might not fully capture the effects of participating in the *Ohio State EmPOWERment Program*; and the generalizability of the findings might be compromised because of (2) the relatively small sample size and (3) the context of a single institution – we are able to provide several conclusions.

Across the capacities that are examined in the sequential linear regression analyses, the consistent significance of *pre-test scores* for *innovation self-concept*, *proactivity*, *social networking*, *risk-taking or tolerance*, *creative capacity*, and *intention to innovate* as predictors of *post-test capacities* is notable. In fact, all the constructs in the Cognitive Scale satisfy the necessary assumptions – a finding that suggests this scale has a particular robustness for assessing the development of innovation capacities in this study. *Pre-test scores* account for a substantial proportion of the variance in *post-test scores*, and highlights the importance of initial capacity levels on subsequent development. The explanatory power of *social networking capacity* and *creative capacity* is also particularly noteworthy. The results indicate that each of these constructs account for at least 60% of the variance in *post-test* scores. This explanatory power underscores the importance of these capacities in forecasting academic performance as measured by *post-test* assessments. Such findings align with the notion that baseline competencies shape subsequent educational trajectories. There are many implications for higher education, and we highlight the necessity of considering initial student competencies when devising pedagogical strategies and curricular designs. Students with higher initial capacities in these domains may experience an amplified developmental trajectory, which may result in superior *post-test* outcomes. This relationship between initial and subsequent capacity warrants further investigation, particularly to discern the directionality and causality of these associations.

Participating in the *Ohio State EmPOWERment Program* appears to be beneficial. For example, with the *creative capacity* construct, there is a substantial increase in explanatory power when adding *group participation* to the Innovation Self-Capacity Model for the Group Participation Model. More broadly, participation in the *Ohio State EmPOWERment Program* may increase *innovation self-concept*, *proactivity*, *creative*, and *intention to innovate* capacities. This finding suggests that the strategies that are implemented in the *Ohio State EmPOWERment Program* cultivate these facets of innovation. These findings are consistent with the constructive-developmental theory that documents how structured educational experiences can trigger psychological transformations and lead to higher-order competencies (Kegan, 1982, 1994; Kegan and Lahey, 2009). Baseline measures of *social networking* and *risk-taking or tolerance* are determinants of these future capacities, but the results suggest that: (a) these capacities may require more personalized or experiential learning opportunities than provided by the *Ohio State EmPOWERment Program*, (b) these skills are more rooted in prior experience, or (c) they may develop over a longer time frame. This latter possibility calls for longitudinal studies that last for more than a year. Future work could investigate the underlying factors and potential interventions that may enhance graduate students' capacities to network and tolerate risk.

7 References

- [1] National Academy of Engineering and E. National Academies of Sciences and Medicine, *Environmental Engineering for the 21st Century: Addressing Grand Challenges*. Washington, DC: The National Academies Press, 2019. doi: 10.17226/25121.
- [2] H. Andersen, “Collaboration, interdisciplinarity, and the epistemology of contemporary science,” *Studies in History and Philosophy of Science Part A*, vol. 56, pp. 1–10, Apr. 2016, doi: 10.1016/j.shpsa.2015.10.006.
- [3] D. Sachmpazidi, A. Olmstead, A. N. Thompson, C. Henderson, and A. Beach, “Team-based instructional change in undergraduate STEM: characterizing effective faculty collaboration,” *IJ STEM Ed*, vol. 8, no. 1, p. 15, Dec. 2021, doi: 10.1186/s40594-021-00273-4.
- [4] L. Ryser, G. Halseth, and D. Thien, “Strategies and Intervening Factors Influencing Student Social Interaction and Experiential Learning in an Interdisciplinary Research Team,” *Res High Educ*, vol. 50, no. 3, pp. 248–267, May 2009, doi: 10.1007/s11162-008-9118-3.
- [5] B. A. Burt, B. D. Stone, R. Motshubi, and L. D. Baber, “STEM validation among underrepresented students: Leveraging insights from a STEM diversity program to broaden participation,” *Journal of Diversity in Higher Education*, vol. 16, no. 1, pp. 53–65, Feb. 2023, doi: 10.1037/dhe0000300.
- [6] A. M. Corbacho et al., “Interdisciplinary higher education with a focus on academic motivation and teamwork diversity,” *International Journal of Educational Research Open*, vol. 2, p. 100062, 2021, doi: 10.1016/j.ijedro.2021.100062.
- [7] D. DeHart, “Team science: A qualitative study of benefits, challenges, and lessons learned,” *The Social Science Journal*, vol. 54, no. 4, pp. 458–467, Dec. 2017, doi: 10.1016/j.soscij.2017.07.009.
- [8] S. Dooling, J. K. Graybill, and V. Shandas, “Doctoral Student and Early Career Academic Perspectives on Interdisciplinarity,” in *The Oxford Handbook of Interdisciplinarity*, 2nd ed., R. Frodeman, Ed., Oxford University Press, 2017, pp. 573–585. doi: 10.1093/oxfordhb/9780198733522.013.46.
- [9] B. S. Selznick and M. J. Mayhew, “Measuring Undergraduates’ Innovation Capacities,” *Res High Educ*, vol. 59, no. 6, pp. 744–764, Sep. 2018, doi: 10.1007/s11162-017-9486-7.
- [10] N. Swayne, B. Selznick, S. McCarthy, and K. A. Fisher, “Uncoupling innovation and entrepreneurship to improve undergraduate education,” *JSBED*, vol. 26, no. 6/7, pp. 783–796, Dec. 2019, doi: 10.1108/JSBED-04-2019-0122.
- [11] C. Bock, D. Dilmetz, B. S. Selznick, L. Zhang, and M. J. Mayhew, “How the university ecosystem shapes the innovation capacities of undergraduate students – evidence from Germany,” *Industry and Innovation*, vol. 28, no. 3, pp. 307–342, Mar. 2021, doi: 10.1080/13662716.2020.1784710.
- [12] B. S. Selznick, L. S. Dahl, E. Youngerman, and M. J. Mayhew, “Equitably Linking Integrative Learning and Students’ Innovation Capacities,” *Innov High Educ*, vol. 47, no. 1, pp. 1–21, 2021, doi: 10.1007/s10755-021-09570-w.

- [13] B. S. Selznick and M. J. Mayhew, "Developing First-Year Students' Innovation Capacities," *The Review of Higher Education*, vol. 42, no. 4, pp. 1607–1634, 2019, doi: 10.1353/rhe.2019.0077.
- [14] M. J. Mayhew, B. S. Selznick, L. Zhang, A. C. Barnes, and B. A. Staples, "Examining Curricular Approaches to Developing Undergraduates' Innovation Capacities," *The Journal of Higher Education*, vol. 90, no. 4, pp. 563–584, Jul. 2019, doi: 10.1080/00221546.2018.1513307.
- [15] R. Kegan, *The Evolving Self*. Harvard University Press., 1982. [Online]. Available: <https://doi.org/10.2307/j.ctvjz81q8>
- [16] R. Kegan, *In over Our Heads: The Mental Demands of Modern Life*. Cambridge, MA: Harvard University Press, 1994.
- [17] R. Kegan and L. L. Lahey, *Immunity to change: How to overcome it and unlock potential in yourself and your organization*. Harvard Business Press., 2009.
- [18] J. Piaget, *The equilibration of cognitive structures: The central problem of intellectual development*. Chicago: University of Chicago Press (original work published 1975), 1985.
- [19] E. H. Erikson, *The problem of ego identity*. *Journal of American Psychoanalytic Association*, 4,56–121, 1956. [Online]. Available: <https://doi.org/10.1177/000306515600400104>
- [20] L. Kohlberg, *The Development of Modes of Thinking and Choices in Years 10 to 16*. University of Chicago: Ph. D. Dissertation, 1958.
- [21] R. Kegan, *What "form" transforms?: A constructive-developmental approach to transformative learning*. Routledge, 2018.