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Uncovering Learning Outcome Profiles in a Multi-Institutional STEM Outreach Program: A Latent Profile Analysis Approach

Sohee Kim, University of South Alabama

Dr. Sohee Kim is an assistant professor in the Department of Counseling and Instructional Sciences at the University of South Alabama. Her research expertise spans item response theory, dimensionality, scale development and validation, differential item functioning, and machine learning in the educational and psychological measurement field. Additionally, she had an experience related to AI perception and AI literacy research. Currently, she serves as PD and Co-PD of two internal grants at the University of South Alabama; one is the project related to the differential item functioning, and the other is the project related to the scale development (Social Justice Behavioral Measure Validation Study).

Dr. Jae Hoon Lim, University of North Carolina at Charlotte

Dr. Jae Hoon Lim is a Professor of Educational Research at the University of North Carolina at Charlotte. Her research explores the dialogical process of identity construction among students of color and examines the impact of sociocultural factors on their academic experiences. She has served as a co-PI for multiple federal grant projects, including a 1.6 million grant from the National Science Foundation. Her research has been published in several premier journals, including the Journal of Educational Psychology, Journal of Higher Education, and Race, Ethnicity, and Education. She is a contributing author to several books published by Oxford University Press and the University of California Press. She served as President for the Korean American Educational Researchers Association, including President in 2013-2014, and Chair of the KAERA Board of Directors in 2019-2020.

Mr. Jerry Lynn Dahlberg Jr, University of Tennessee, Space Institute

Jerry Dahlberg is the Director of Research at the University of Tennessee Space Institute. Prior to joining UTSI, he was an Assistant Teaching Professor and Senior Design Committee Chair at the University of North Carolina at Charlotte. He received a B.S. degree in Mechanical Engineering Science in 2014, M.S. in Mechanical Engineering in 2016 and PhD in Mechanical Engineering in 2018 from the University of North Carolina at Charlotte.

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Abstract

This empirical full paper reports the results of statistical analyses from a large mixed-methods evaluation study examining the learning outcomes of diverse students participating in a multi-institutional summer engineering enrichment program. The summer camp program was jointly implemented by a Predominantly White Institution (PWI) and a Historically Black College and University (HBCU). The study utilizes post–summer camp survey data collected from 140 middle and high school students during the 2023 and 2024 program cycles. The survey included self-reported learning outcome measures theoretically grounded in Bloom's Taxonomy, Cognitive, Affective, and Psychomotor [1] [2], to assess students' perceived gain in knowledge, motivation, and hands-on skill development resulting from the summer camp activities, as well as other instruments for students' camp experiences and STEM career interests. By employing a Latent Profile Analysis (LPA) combined with multinomial logistic regression, we identified distinct subgroups of camp participants based on students' self-reported learning outcomes and heterogeneity in their camp experiences. Our analytic outcomes elucidate how varying levels of engagement, motivation, and experiential quality shape the learning trajectories of different student subgroups, challenging the common assumption of a homogeneous student population in summer enrichment curriculum development and implementation.

Keywords: Latent Profile Analysis, Multi-institutional Collaboration, STEM Outreach, Learning Outcomes

Introduction

High-quality STEM education and robust STEM workforce development have been widely recognized as top national priorities, as they are pivotal building blocks for innovation and economic prosperity in the nation [3]. To boost young people's interest in STEM fields and science and technology careers, both federal and state government agencies and educational institutions have devised many strategies. Among these efforts, STEM-focused summer camps and enrichment programs have become a popular and practical way to spark and sustain young students' STEM interest, as informal learning plays a significant role in shaping one's career aspirations [4]. Even though the precise number of summer enrichment camps nationwide is not known, in 2023, over 80% U.S. public schools offered some type of summer enrichment programming; 78% of the schools provided academically focused summer programs, which are likely to include some STEM learning components [5]. Afterschool Alliance's executive summary also documents significant growth in STEM learning opportunities outside the regular school [6]. Notably, a wide range of federal agencies' grants, including National Science Foundation (NSF) and National Institutes of Health (NIH), supported the expansion of STEM summer camps through various programs (e.g., ITEST, SEPA). These federal grants have explicitly supported young students' informal STEM learning, career awareness, and workforce development, while state/local governments, private foundations, and STEM-intensive corporations routinely co-sponsor camps as part of regional talent pipeline and community investment strategies.

While the long-term impact of summer STEM enrichment programs on students' academic performance in STEM subjects and later career decisions is still under scrutiny, researchers generally agree that well-designed STEM summer camps can produce measurable gains in STEM-related learning and other closely related constructs (e.g., content knowledge, self-efficacy, and perceived competence), particularly when camps are structured around hands-on, problem-based, or constructivist learning experiences. For example, Mohr-Schroeder and colleagues found positive pre–post camp shifts in students' STEM motivation and interest in a multi-day middle grades STEM camp evaluation, supporting the widely recognized claim that even short, intensive STEM enrichment experiences can generate important learning-related outcomes even within a single week [7].

Educational researchers have long recognized that learning is not simply about cognitive process but involves the whole scope of human development. As a result, well-designed summer camp evaluations typically adopt an integrated approach that recognizes its impact on student motivation, STEM identity/affinity, and career interest, while paying due attention to students' affective experience, a dimension increasingly reported as a pivotal mechanism linking informal learning to longer-term participation [7] [8]. Kong et al.'s large-sample longitudinal evidence further strengthens this argument [4]. In their study with over 1,500 middle school students across five states, they found that student participation in science summer camps was associated with a higher likelihood of later reporting interest in science and engineering careers, suggesting that camps may contribute to durable career-oriented expectations, even if making a direct causal inference remains methodologically challenging. To make even one step further, a recent summer camp evaluation study by Kudaisi et al. explicitly treats enjoyment, positive experiences, and perceived relevance as central outcomes (and potential mediators) rather than interesting byproducts, reflecting a growing consensus that affective engagement is not separable from cognitive learning in STEM informal learning environments, such as summer camp programs [9]. Taken together, the current literature supports an integrated program design and implementation that encompasses learners' holistic development, which can generate a positive impact. In other words, summer STEM enrichment camp programs are likely to succeed when they create a motivating, socially supportive environment in which students enjoy authentic STEM activity, experience success, and can connect that experience to their potential future selves in STEM, thereby reinforcing both learning and STEM career commitment.

This growing consensus on the importance of non-cognitive dimensions in supporting young students' STEM learning and career commitment yields a clear design implication: if camps are evaluated (and therefore designed) narrowly around cognitive learning outcomes, they risk undervaluing precisely the features that make camps most impactful (e.g., joy, social connection, and identity-safe exploration). Therefore, STEM summer camp design and implementation should be deliberately engineered to advance both cognitive learning and affective experiences (enjoyment, confidence, belonging, and perceived relevance), because these affective dimensions are not peripheral but central to why short, intensive informal STEM experiences can influence adolescents' longer-term engagement and career trajectories.

One critical void in our understanding of STEM summer camps' impact is the underlying mechanism by which summer camps produce the observed tangible effects on learning outcomes, especially the roles of enjoyment, belonging, and positive experiences in enabling deeper engagement with challenging content. Despite the growing number of STEM summer camps and related evaluation research, we know very little about the inner workings of these variables and possible variations among different groups of students who participate in summer camps. Our study intends to address this significant void in existing literature through a close examination of the key variables based on our summer camp data.

Conceptual framework: Integrated outcome design

The summer camp program design and evaluation methods were grounded in a multi-layered theoretical and conceptual framework, as each facet of the mixed-method evaluation research is supported by unique theoretical underpinnings that share core principles of constructivist epistemology and associated learning theories.

In particular, the student pre- and post-camp surveys that included the Learning Outcome Measures and Camp Experience Measures reflected the principles of what we want to refer to as "*Integrated Outcome Design*," an outcomes-first approach that intentionally integrates cognitive, affective, and psychomotor/skill/practice outcomes and aligns learning activities and assessment evidence accordingly [10] [11]. We designed the student learning outcome measure based on Bloom's taxonomy (cognitive, affective, and psychomotor domains). Two other theories, Biggs' theory of constructive alignment and Kolb's experiential learning theory, both well aligned with Bloom's original work, also guided our curriculum design, implementation, and assessment. Biggs and Tang's and Fink's work emphasize the importance of alignment across domains, not just within the cognitive domain, and elucidates the links across curriculum content, instructional activities, learning outcomes, and assessment methods [10] [12]. Likewise, experiential learning theory highlights the context-dependent nature of human experience, thereby supporting the integration of doing, meaning-making, and identity formation, especially in STEM environments.

Study contexts: Summer camp curriculum and implementation

The statistical analysis presented in this paper is part of the larger mixed-methods program evaluation that included multiple surveys, interviews, and document data. The purpose of the program evaluation was to assess the overall impact of STEM enrichment summer camps on participating high and middle school students and collaborating schoolteachers, all recruited from rural areas in two southern states.

Guided by the Integrated Outcome Design Approach and Constructivist Learning Theory, a team of faculty and staff members from three different institutions launched an engineering summer camp with dual goals: to support rural middle and high school students build a foundational engineering knowledge and technical competencies while providing a positive experience of STEM engagement that is pivotal to generating long-term affective and motivational outcomes. Our summer camp program was exclusively targeted at rural school students in Northern Alabama and Southern Tennessee, where access to rigorous STEM subject instruction and high-quality STEM enrichment opportunities is limited. To allow easy access for the targeted student population, we offered each camp at public school sites in their rural communities. The camp curriculum was designed for a five-day, weeklong camp. Yet, two camps, one in 2023 and the other in 2024, were cut short due to having a Federal Holiday during the week. In total, seven summer camps were held: three in 2023 and four in 2024. The project team traveled to each campsite, transporting key equipment and resources (e.g., a wind tunnel, 3D printers, and laptops) to allow campers to have authentic hands-on experiences.

The camp curriculum was developed and implemented by a joint team of six faculty members from two institutions, one PWI and one HBCU (2 PWI and 4 HBCU faculty members). All student participants engaged in various learning modules, including (1) Hypersonics, (2) Additive Manufacturing, (3) Composite and High-Temperature Materials, (4) Paper Airplane Challenge, (5) Wind Tunnel Exploration, (6) Engineering Rockets, (7) Artificial Intelligence (AI), and (8) Cybersecurity. Each module was designed to integrate both engineering and technology concepts while promoting problem-solving, collaboration, and creative design. The activities were aligned with specific learning outcomes targeting cognitive understanding, motivational engagement, and hands-on skill development—corresponding to the three domains of Bloom's Taxonomy: Cognitive, Affective, and Psychomotor [1] [2].

During the first year, five graduate and three undergraduate students were hired as teaching assistants (TAs) and led sessions on their assigned topics with some hands-on activities. The three HBCU undergraduate engineering students worked most closely with campers, covering more than 70% of the summer camp topics and activities. During the second year, four PWI graduate students and three HBCU undergraduate students were hired to lead the revised curriculum. One HBCU undergraduate student participated in both years' programs. All summer camps included at least two field trips, such as visiting the PWI and HBCU campuses and other industry facilities. These field trips were led by various project team members, yet HBCU undergraduate students played the most significant role in leading the camp program and field trips. The evaluation team reported the outcomes of qualitative data in previous publications [13] [14].

Methods

Participants

Participants in the study included 140 middle and high school students from diverse demographic backgrounds who attended one of the seven engineering summer camps implemented in 2023 and 2024. Of these, 67 identified as male, 64 as female, and 8 as non-binary/third gender. Regarding racial and ethnic identity, 76 students identified as White, 41 as Hispanic/Latinx, and 16 as Black or African American. Additionally, 41 students reported speaking English as a second language (ESL), while 98 were native English speakers.

Instruments

This paper is based on the student post-camp survey, which was completed by all campers at the end of each weekly camp. The post-camp survey included four sub-sections: 1) Learning Outcome Measures (20 items), 2) STEM Career Interest and Commitment Measures (6 items), 3) Learning Experience Survey (10 items), and 4) Demographic Information (5 items).

The Learning Outcome Measure was designed to assess students' perceived learning outcomes across the three domains of Bloom's Taxonomy—Cognitive, Affective, and Psychomotor (Bloom, 1964)—reflecting students' perceived gains in knowledge, motivation, and hands-on skills developed through camp participation. The instrument consisted of 20 items distributed across the three domains: (1) Cognitive learning (10 items; e.g., "I can tell how hypersonic field is related to aerospace and defense challenges."), (2) Affective learning (6 items; e.g., "I can see the value of Additive Manufacturing applications in aerospace and defense. "), and (3) Psychomotor learning (4 items; e.g., "I can build and test paper airplanes of different types."). Each item was rated on a five-point Likert scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree). Descriptive analyses indicated that participants reported generally positive learning experiences across all domains. The Cognitive domain had a mean of M = 3.79 (SD = 0.65), the Affective domain M = 3.88 (SD = 0.69), and the Psychomotor domain M = 3.97 (SD = 0.74). These findings suggest that students perceived balanced and meaningful development across cognitive understanding, motivational engagement, and hands-on skill application.

The Student Learning Outcome Measure was developed in collaboration between the summer camp curriculum designers, who are engineering professors and therefore respective content experts, and the assessment lead, an educational researcher specialized in STEM program evaluation. While the entire survey instrument has not yet been empirically validated, it is well-grounded theoretically and has content validity ensured through multiple content expert collaborations.

The post-camp survey also included two subsequent sections that assessed the quality of campers' program experiences and STEM career interests, including specific items related to naval engineering. The Learning Experience Survey consists of seven Likert-scaled items, two rank-order items, and one open-ended question. The STEM Career Interest and Commitment Measure included six Likert-scaled items. Most of the survey items in these two sections were adapted from previously validated measures widely used for evaluating informal STEM enrichment programs.

Statistical analysis

Prior to the main analyses, data were screened and descriptive statistics were examined to assess distributions of study variables and participant characteristics. To identify distinct patterns of students' perceived learning outcomes across the cognitive, affective, and psychomotor domains, a Latent Profile Analysis (LPA) [15] was conducted using post-program survey data grounded in Bloom's Taxonomy.

Model selection was guided by multiple fit indices, including the Akaike Information Criterion (AIC) [16], Bayesian Information Criterion (BIC) [17], sample-size adjusted BIC (ABIC) [18], entropy values, the Lo–Mendell–Rubin adjusted test (LMR) [19] and the Bootstrapped Likelihood Ratio Test (BLRT) [20]. The optimal number of profiles was determined based on overall model fit, parsimony, classification accuracy, and theoretical interpretability.

Following identification of the optimal latent profile solution, multinomial logistic regression analyses were conducted to examine predictors of profile membership. Predictor variables included students' demographic characteristics, learning experiences, STEM career interest, and psychosocial factors such as program satisfaction, self-efficacy, resilience, and educational aspirations.

All LPA models were estimated using Mplus 8.0 [21], and multinomial logistic regression analyses were conducted using SPSS Statistics 29.0.

Results

Results from the LPA indicated that a three-profile solution—low, middle, and high learning outcome groups—best represented the data both statistically and theoretically. All three groups demonstrated balanced levels across the cognitive, affective, and psychomotor domains, suggesting holistic development through the program. However, the groups differed in the overall magnitude of perceived learning, representing distinct levels of engagement and achievement. Participants in the High group reported the highest mean scores in all three domains (Cognitive = 4.60, Affective = 4.67, Psychomotor = 4.76), followed by the Middle group (3.81, 3.93, and 3.95, respectively). The Low group exhibited the lowest mean scores across domains (2.85, 2.93, and 2.90, respectively). Overall, the pattern suggests a consistent differentiation among groups across the three domains of Bloom's Taxonomy, with the High group demonstrating strong proficiency in all areas, the Middle group showing moderate competency, and the Low group reflecting limited learning outcome development. (Table 1)

Table 1

Descriptive Statistics for Demographic Characteristics by Latent Group (*n*, %)

Variable	Low	Middle	High
Gender			
Male	15 (53.6%)	37 (45.1%)	15 (51.7%)
Female	12 (42.9%)	39 (47.6%)	13 (44.8%)
Other	1 (3.6%)	6 (7.3%)	1 (3.4%)
Race/Ethnicity			
White	14 (50.0%)	37 (45.1%)	25 (86.2%)
Students of Color	14 (50.0%)	45 (54.9%)	4 (13.8%)
ESL Status			
Non-ESL	20 (71.4%)	51 (62.2%)	27 (93.1%)
ESL	8 (28.6%)	31 (37.8%)	2 (6.9%)

To further explore factors differentiating these profiles, multinomial logistic regression analyses were conducted. When comparing the middle group to the low group, learning experience emerged as a significant predictor (B = 2.084, Wald = 11.132, $p = .001$, Exp(B) = 8.039), indicating that students reporting more positive learning experiences were about eight times more likely to belong to the middle group than the low group. Comparing the high group to the low group revealed two significant predictors, STEM naval career interest (B = 2.939, Wald = 7.845, $p = .005$, Exp(B) = 18.903) and learning experience (B = 4.118, Wald = 14.184, $p < .001$, Exp(B) = 61.415), suggesting that strong career interest and rich learning experiences substantially increased the likelihood of belonging to the high learning outcome group. Finally, when comparing the high group to the middle group, both STEM naval career interest (B =

1.890, Wald = 4.851, p = .028, Exp(B) = 6.622) and learning experience (B = 2.033, Wald = 4.852, p = .028, Exp(B) = 7.640) remained significant, underscoring the combined influence of career motivation and experiential quality in achieving the highest level of learning outcomes.

Discussions

As a whole, the study results highlight that positive learning experiences and clear STEM career interests are powerful catalysts for deeper engagement and learning gains. Grounded in Integrated Outcome Design, indebted to Bloom's original work and to later scholars' integrated approaches to student learning and STEM curriculum development, this study offers a nuanced understanding of the interconnected relationships across multiple domains of student learning shaped by motivational and affective factors, as well as how different subgroups of learners engage with informal STEM enrichment programs.

The statistical results, in particular, highlight three main insights. First, the three-profile solution reflects the diverse engagement levels among camp participants, emphasizing that enrichment programs serve a heterogeneous learner population. Even students with initially low engagement benefited holistically across Bloom's domains, suggesting that the program successfully fostered balanced learning. Second, learning experience quality emerged as the most consistent and powerful predictor of higher learning outcomes. This underscores the importance of experiential design, mentoring, and inclusive instructional strategies that enhance perceived learning value. Third, STEM career interest, especially in naval or engineering pathways, differentiated high-achieving students from others. This finding supports prior literature suggesting that authentic, career-connected experiences can strengthen students' sense of purpose and identity in STEM [22] [23].

We believe that these findings fill a significant gap in the existing literature by elucidating the mechanism by which affective and psychological dimensions shape cognitive learning outcomes. These insights provide practical implications for designing effective, equitable, student-centered, and career-connected outreach programs that nurture diverse students' cognitive, affective, and psychomotor development, offering a clear and deeper understanding of their interconnectedness and the holistic nature of student learning that extends beyond the cognitive domain.

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