

Using a Taxonomy to Categorize Physiological Affect Statements to Determine Their Impact on Other Sources of Self Efficacy

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Abstract

To prevent students from leaving engineering and computing disciplines, new ideas, complex theories, and innovative ideas are needed. These ideas in mind inform the authors' application of the problem-solving methods of systems engineering in combination with the laws of human behavior science, without the use of advanced mathematical logic. The idea behind this concept suggests there is logic to human behavior which cannot be explained solely through traditional mathematical algorithms. By layering complex theories, a new method of understanding the influences in sources of Self Efficacy (SE) as described by Albert Bandura was proposed in other work. This paper builds on that work demonstrating the development of tools to support how students process their experience with content in engineering and computer science programs. The four sources of SE include three tangible and one intangible. The three tangible sources are: mastery experience (content), social persuasion (faculty/instructors), and vicarious experience (student peers). Physiological affect is the intangible SE source, most easily explained as feelings and emotions. Recent work suggests using physiological affect statements as a filter through which the student experience with content, faculty, and student peers provides insight into how a student processes their experiences and then interacts with their environment. This paper demonstrates the value of a taxonomy to direct categorization of physiological affect statements. This work seeks to provide methods for increasing understanding of the physiological affect to create more effective responses for the student experience and increase persistence in engineering and computer science disciplines.

1.1| Introduction

Extensive research has been conducted on retention in engineering and computer science. Additionally, universities have invested significant financial and human resources in the development and operation of programs dedicated to facilitating the successful completion of degrees in these fields. Strategies such as creating project-based clubs and academic learning centers support application of knowledge outside the classroom, contributing to experience with engineering and computer science content [1], [2]. Bridge programs, research opportunities, and student group centers add to academic confidence while strengthening ties to people within an academic community [3], [4], [5], [6]. Retention literature is closely tied to that of Self Efficacy (SE) and the value of Albert Bandura's research [7]. At the core of Bandura's work is a person's belief they can repeatedly engage with something challenging and eventually reach their goal [8], [9]. The four sources of SE, as explained by Bandura are: 1. Mastery experiences (content); 2. Social persuasion (from a recognized expert); 3. Vicarious experience (with peers at the same level of learning); and 4. Physiological affect (emotions & feelings). These focus on the components that influence the internal process a person goes through when they are working

toward a goal and experience either challenge or ease of performance. This process influences how a person chooses to engage with their environment.

Research in engineering and computing disciplines around SE topics has created questions to classify student responses related to drive, motivation, or interest [10], [11]. In other cases, the researcher has focused physiological responses toward content being predictors of building SE [12]. While these findings contribute important perspectives the picture presented is 2-dimensional and leaves out the rest of the story with students who live their lives in context to their environment, a perspective introduced by Urie Bronfenbrenner [13] whose work focused on the ecology of a person's environment.

Within engineering education, early retention research describes environmental factors, such as content mastery, interactions with peers and engagement with faculty, contribute as much to persistence as internal influences [14]. The internal and external components of this problem suggest a need to create a theoretical framework to study retention from a full 360-degree, student perspective. Doing so increases the ability to create more effective programs (external) *and* supports the student's decision (internal) to approach challenging subjects.

1.2 | Theoretical Framework

This paper builds on research combining two complex theories to create a robust framework design to study the 360-degree student experience. Adding Urie Bronfenbrenner's, post-1990's version of *bioecological model of human development* to *SE theory* (bioecological model) to the equally influential sources of SE completes the picture by connecting external and internal process informing persistence. [15], [16], [17]. Briefly, the constructs of bioecological model consider the environmental settings surrounding a student and their combined, contextual influence on their development over time. Specifically, the environment constructs are known as: *microsystem*, *mesosystem*, *exosystem*, and *macrosystem*. These, combined with the components of *Process-Person-Context-Time* (PPCT) demonstrate the intricately woven tapestry of human development within context. This theoretical framework is visually demonstrated in Figure 1.2(a) with bioecological model situated external to the student and SE theory internal to the student. The external human systems surrounding the student connect with the internal systems within through a filter described by Bronfenbrenner (1995b, 1995a) as *developmentally instigative characteristics*, aligning with *physiological affect* a source of SE [17]. This filter is used to make sense of one's environment and determine how to respond.

Retention research overall has included studies using either SE theory or bioecology model. In engineering and computing education research focusing on sources of SE, mastery experience is more heavily weighted as a predictor of persistence [11], [18], [19], [20]. Studies focusing on structure of the environment using either Bronfenbrenner's ecology or bioecology models, favor student perception of their environment and how that might inform persistence, engagement or interest with engineering or technology programs [21], [22], [23]. More recent work by Swan (2015; 2011), Neber [26], and Clark [27] have begun to combine complex theories together to increase understanding of the student experience. Results have led to a more comprehensive, 360-degree perspective which authentically describes what factors influence the student

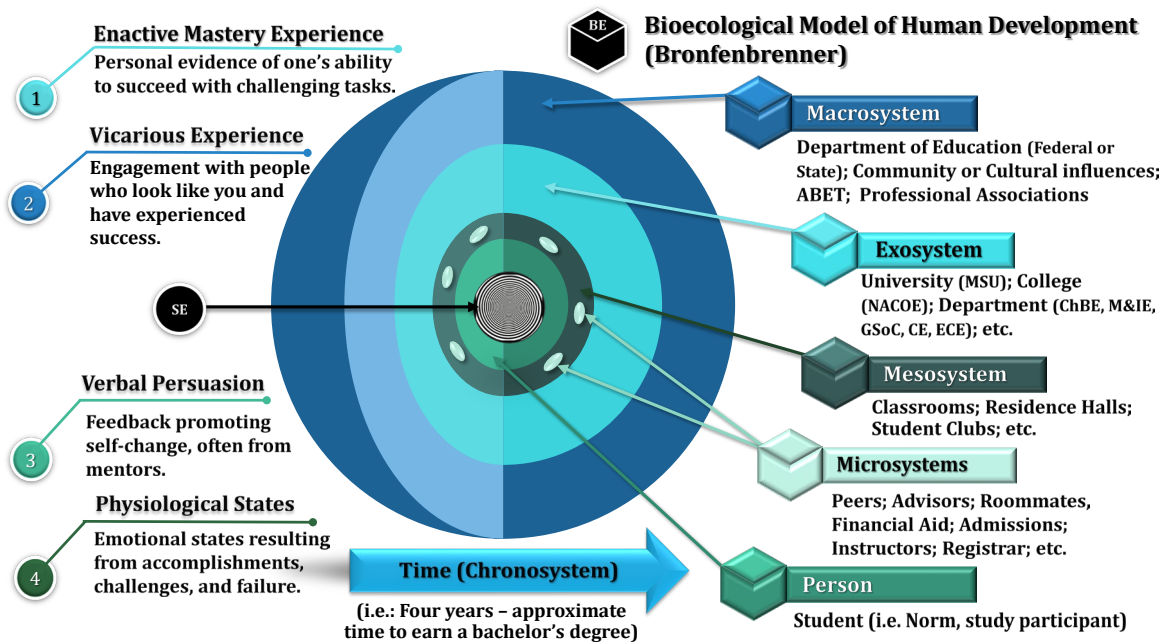


Figure 1.2(a): Theoretical Framework - SE Theory and Bioecological Model of Human Development

experience and why they matter to persistence. This adds value to the development and implantation of programs intended to meet student needs while they are learning complex material and address retention goals. It is much like building an electrical system with pre-programmed devices. If coding of these devices aligns with the designer's objectives, they are an asset and assist with efficient system development. The moment the needs of the designer conflicts with the resources developed (with different objects in mind), they become liabilities to project completion.

Historically, sources of SE have been presented in a pie chart with four equal quadrants representing mastery experience, social persuasion, vicarious experience, and physiological affect shown in Figure 1.2(b) [18], [28], [29]. A significant amount of literature focuses on understanding the power each source of SE has on an individual's decision to continue engaging with difficult content. Not surprising, an individual's perception, or experience with challenging material has been shown quantitatively to have the greatest impact on one's repeated engagement with challenging content. Physiological affect, a person's physical and emotional response to their environment, has measured to have the least impact [18], [30], [31], [32]. A qualitative dissertation study completed in fall of 2022, in combination with other work by one of the authors presents a new perspective suggesting that sources of SE inform the fluidly between the individual and the environment [27], [33], [34]. The study presented a model to understand the fluid, contextual interactions between the environmental sources of SE and physiological affect which is a membrane through which a person makes sense of their experience and then chooses how to behave.



Figure 1.2(b): Common of SE Sources Visual

1.3 | Environment and SE Model

The basis of this paper is a new model for describing how sources of SE influence an individual's engagement with their environment. Figure 1.3 visually presents the Environment and SE Model. At the center of this model is the student, surrounded by the physiological affect membrane through which the student processes their engagement with the environment and more tangible sources of SE. Students experience positive (+) and negative (-) interactions with their environment as they learn new content (mastery experience) and interact with faculty or instructors (social persuasion) and their peers (vicarious experience). It is important to comment on the dynamic and fluid nature of these interactions as students are living their lives in context. A mix of positive and negative interactions is ideal for supporting engagement as these stimulate decisions [7].

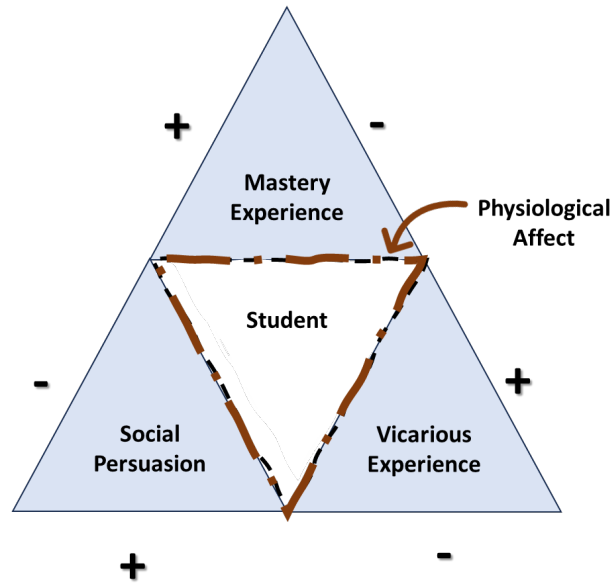


Figure 1.3: Environment and SE Model

Using this model (Figure 1.3) of understanding sources of SE, the authors developed a taxonomy to filter physiological affect statements into the three tangible SE categories (mastery experience, social persuasion, and vicarious experience). The purpose of this qualitative study was to understand the relationship between physiological affect and its influence on SE sources, particularly social persuasion, and vicarious experiences. The purpose of this qualitative study was to understand the relationship between physiological affect, SE, and the influence of social persuasion and vicarious experiences. The study explores how physiological affect manifests itself in relation to SE and aims to understand how the power of social persuasion and vicarious experiences may influence a person's perception of their own capabilities related to engineering or computer science content. When controlling for physiological affect within student statements, the hypothesis is the strength of mastery experience would be affected. This paper describes the findings from applying a taxonomy lens to data exploring 1st and 2nd year engineering and computer science students' perception of their academic SE related to course content. Early work by Rasmussen et al. [35] and Curry et al. [36], in combination with more recent applications by Kittelman et al. (2018; 2020) demonstrates use of a taxonomy as a tool to manage human activity systems. Careful construction and application can provide an effective method for making sense of signs (or responses) to the environment and increase what is understood about developing academic SE.

1.4 | Taxonomy Tool Development

The goal was to investigate the student experience through their qualitative responses using a taxonomy developed to classify physiological affect responses into mastery experience, social persuasion, or vicarious experience categories. Taxonomies have been used as a tool to support continuity and an interpretive methodology when survey responses were analyzed [35], [36], [38], [39], [40]. When a topic requires deeper understanding, qualitative research is an appropriate method of investigation [41]. Ensuring validity and trustworthiness can be done by establishing, communicating, and following a clear analysis process [42], [43], [44]. Following is an outline of the research design, taxonomy development, and procedures for gathering and analyzing data.

2 | Methodology

To answer the research question above, a qualitative study was conducted in 2023 to explore engineering and computer science students’ perception of SE. Students enrolled in the study were 100-200 level students pursuing a bachelor’s degree. A phenomenographic approach was employed as this approach is used to understand the range, or variations, of perspectives a phenomenon is experienced. Developed into its own research approach during the 1980s by Marton et al. [45], [46], [47], phenomenography seeks to understand the range, or variations, of perspectives a phenomenon is experienced. It seeks to understand the essence of these experiences to honor a particular moment during an individual’s development in an academic environment (Booth, 1997, 2001). Phenomenography is related to phenomenology but unique in its contribution to understanding human experience in two important respects. First, phenomenography focuses on the ways in which learners differ, both maximizing the potential for variation and honoring the individual experiences of people part of a study [47], [48], [49]. Second, phenomenography takes the phenomenon's experience as the unit of measurement, versus the phenomena itself. Data is then pooled together and analyzed in a systematic, iterative process to identify a set of distinctive categories from which a full collective experience can be described. Analysis seeks to identify the fewest, logically related, categories required to describe the total range of variation in a pool of individual experiences [50].

2.1 | Data Gathering and Description

Students in 100 – 200 level courses in engineering and computer science at a large, 4-year public research institution were the focus population of this study. The focus population totaled 2,802 students enrolled in 1 or more 100 or 200 level engineering or computer science courses. Of this group, 157 participants choose to respond to a survey request for feedback on their experience. Five participants reported having already changed to a major outside the college of engineering, 103 declared an engineering or computer science major and 49 did not indicate a major. Responses to four survey questions focused on persistence were the focus of this study and are detailed in Table 2.1. Responses to the two short answer questions are the scope for this qualitative project. Analysis of all questions would be more appropriate for a separate study.

Table 2.1: Survey Persistence Questions and Number of Responses

Question	Response Options	Responses
Have you ever thought of changing majors or leaving your studies?	Never	22
	Occasionally	59
	Several times	14

	Many times	16
	Non-Responses	46
	Total Responses	157
	Change majors and careers within the STEM fields.	59
	Change major and career field to non-STEM fields within the humanities, social sciences, arts, etc.	20
Which of these options did you consider?	Change to vocational education and training or community college.	5
	Search for a job	15
	Non-Responses	58
	Total Responses	157
If you stayed in an engineering or computer science major, what or who influenced your decision to continue?	Short Answer	75
	Non-Responses	82
	Total Responses	157
If you changed to a major outside of the college of engineering, what or who influenced your decision?	Short Answer	28
	Non-Responses	129
	Total Responses	157

2.2 | Taxonomy Tool Development

Participant responses from two, short-answer survey questions focused on increasing understanding of student engagement with major content. SE is an individual's belief in their ability to accomplish specific tasks or goals they perceive as requiring persistence through challenge. Physiological affect is an intangible SE source that manifests itself in the other three sources (mastery experience, social persuasion, and vicarious experience) which are more easily identified. The taxonomy served to understand and identify a range of affective states involved in student perception of ability to persist with engineering or computer science content. Table 2.2 describes the three categories and assigned physiological affect responses in each area. The first category, mastery experience is also understood as one's perception of task performance, or ability with challenging material. Social persuasion or feedback from perceived experts, typically faculty in an academic setting, is the second. The final category is vicarious experiences with peers or colleagues where visual cues support how a person navigates an environment. Value definition was informed by SE literature, domain analysis guidelines, and research team members' experience [7], [18], [28], [29].

Mastery Experience (<i>task performance</i>)	Social Persuasion (<i>from perceived experts</i>)	Vicarious Experience (<i>with peers/colleagues</i>)
<ul style="list-style-type: none"> - Physiological response to content - Heighted emotion (<i>e.g.: anger, tears, fear</i>) - Skin conductance (<i>e.g.: chills, heat, sweat</i>) - Increased or decreased heart rate 	<ul style="list-style-type: none"> - Encouragement from faculty or instructor. - Verbal engagements that inspire feelings of trust. - Efforts taken by experts to demonstrate, explain, articulate belief in person's ability with content. 	<ul style="list-style-type: none"> - Modeling from peer or colleague - Visual cues of belonging from peers. - Observations of peers in environment that provides an example of how to persist or navigate a challenge.

Table 2.2: Physiological Affect Taxonomy

<ul style="list-style-type: none"> - Voiced belief or perception they can or cannot be successful with challenging content. - Voiced or described personal motivation to repeatedly engage in challenging tasks. - Voiced or described strategies to use resources to support success. 	<ul style="list-style-type: none"> - Voiced influence from perceived experts (positive or negative) informing decision to continue or end engagement with engineering or computer science content. 	<ul style="list-style-type: none"> - Voiced influence from perceived peers (positive or negative) informing decision to continue or end engagement with engineering or computer science content.
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2.3 | Data Analysis Method

Analysis used affective coding methods focusing on emotions tapping into the inner cognitive systems of participants [51]. Previous dissertation work by one of the authors informed this study including its theoretical design, research approach, and data analysis methods. Key concepts pulled from SE theory informed taxonomy design. The iterative, systematic nature of qualitative analysis supports the ability to increase understanding of phenomenon variables which may not be recognized through quantitative research approaches [41]. Domain analysis directed the process for applying the taxonomy to the data set [52]. Participants responded to two questions regarding motivation to stay in an engineering or computer science major or change to a major outside these disciplines. Data was organized in a spreadsheet for analysis using domain analysis, a taxonomy and an iterative, reflective process by the review team followed. Domain analysis uses a symbolic category that includes other related categories within its scope and follows a 7-step process [52]. This iterative process is articulated here and visually described in Figure 2.3.

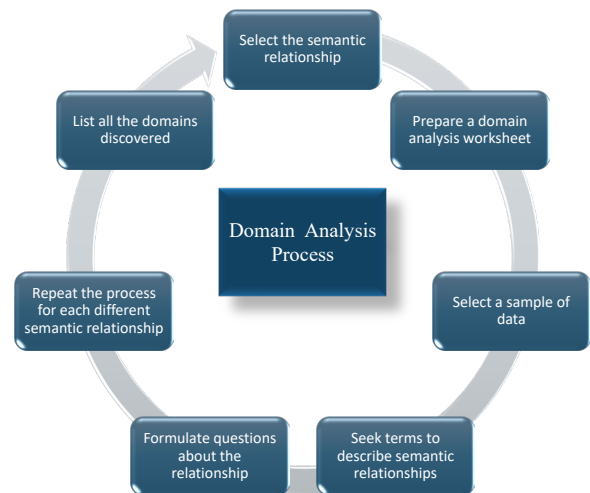


Figure 2.3: Iterative Domain Analysis Process

1. Select the semantic relationship.
2. Prepare a domain analysis worksheet (taxonomy).
3. Select a sample of data.
4. Seek terms to describe semantic relationships.
5. Formulate questions about the relationship.
6. Repeat the process for each different semantic relationship.
7. List all the domains discovered.

2.4 | Data Analysis and Results

Manual analysis of large-size qualitative datasets is complex, error-prone, and laborious. Therefore, integrating AI-based tools into the existing processes can automate and help save a lot of time. In this context, ChatGPT version 3.5 [53], a Generative AI-based large language model, is leveraged to understand the underlying behaviors/patterns captured in the data set. To effectively use such large language models, the prompts must be carefully engineered and should have enough context to guide the model in generating correct responses. The proposed approach consists of the following prompts.

- 1) The first set of prompts, as shown in Figures 2.4(a) and 2.4(b), provides Bandura's research work as a context to classify the students' physiological affect responses into different categories, i.e., mastery experience, social persuasion, or vicarious experience. The response obtained for the first part of the prompt (as shown in Figure 2.4(a)) is to ensure/validate that the ChatGPT understands Bandura's research work and does not hallucinate. After validating the response, the next prompt (as shown in Figure 2.4(b)) is prepared to classify the students' responses into the given categories. The prompt provides clear and specific information (as a context) for guiding ChatGPT response, i.e., assigning the persona, the categories to which the responses should be classified, the question(s) for which the student responses are collected, giving enough time for the model to think, and explicitly mentioning the boundaries in case the model is not sure about prediction for any of the fed students' responses.

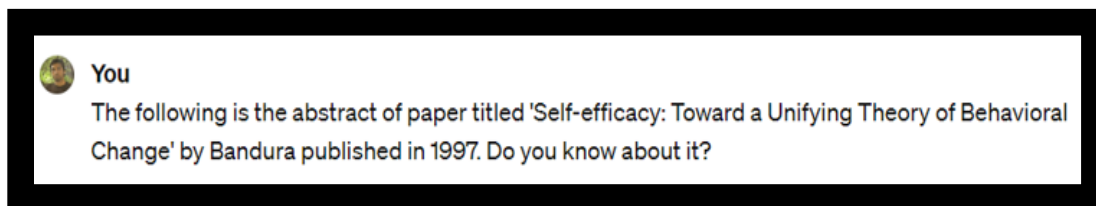


Figure 2.4(a): Providing Bandura's research work as a context.

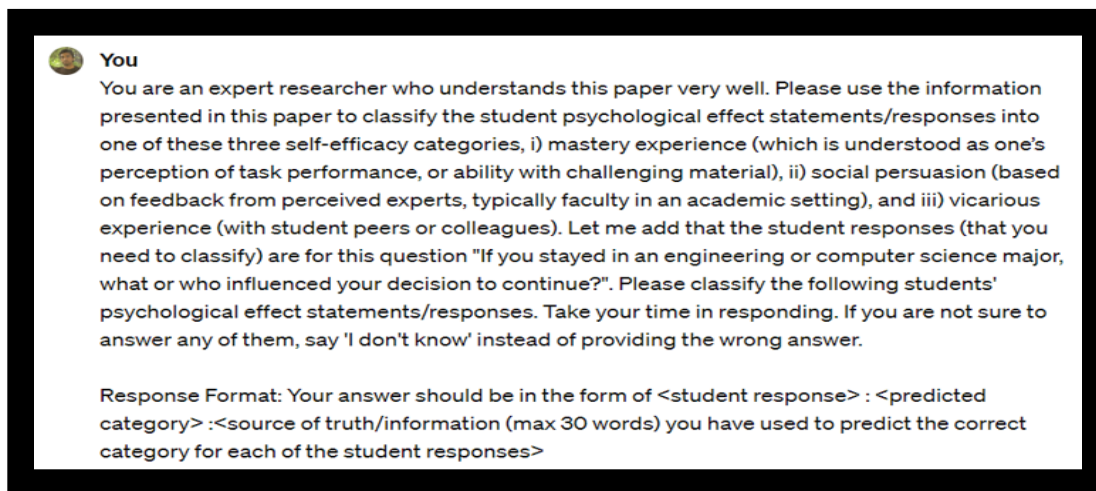


Figure 2.4(b): Prompt prepared for data classification.

- 2) In the second prompt, we have included Bandura’s research work along with some additional information (as a context) using the proposed ‘Physiological Affect Taxonomy’ (as shown in Table 2.2), and then ask ChatGPT to predict the categories for the students’ responses based on this information.

The results obtained for both the prompts are compared using the ‘voting concept’ to validate them further. If the model predicted the same category for a given student's response in both prompts (i.e., the model voted the same category for a given student’s response), it suggests that the model is confident for the predicted category. However, if the model predicted different categories for a given student’s response in both the prompts (i.e., provided different votes), the human-in-the-loop approach is used to manually select/assign the most relevant category for those students’ responses. The following are the observations found.

- For the first question, ‘If you stayed in an engineering or computer science major, what or who influenced your decision to continue?’ Figure 2.4(c) shows that only 7 out of 75 students’ responses (9.33%) are identified, when only using Bandura’s work and a taxonomy, for which the AI model predicted different categories for both the prompts.

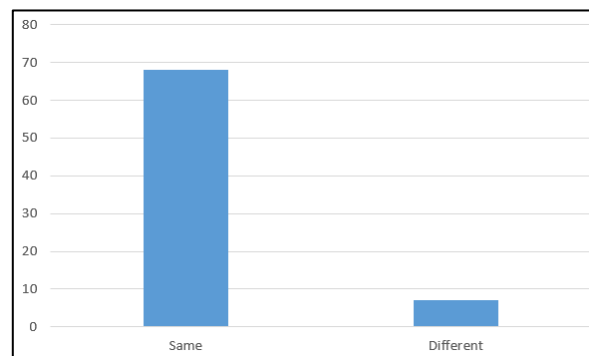


Figure 2.4(c): Predicted Categories for

- For the second question, ‘If you stayed in an engineering or computer science major, what or who influenced your decision to continue?’, Figure 2.4(d) shows that only 2 out of 24 (8.33%) are identified, when using Bandura’s work and a taxonomy, for which the model predicted different categories for both the prompts.

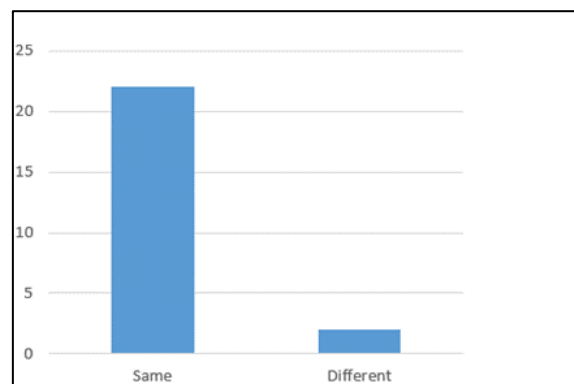


Figure 2.4(d): Predicted Categories for

- Figures 2.4(e) and 2.4(f) show that students' responses are dominated by the "mastery experience" category for both questions, providing valuable insight into the distribution of students’ responses.

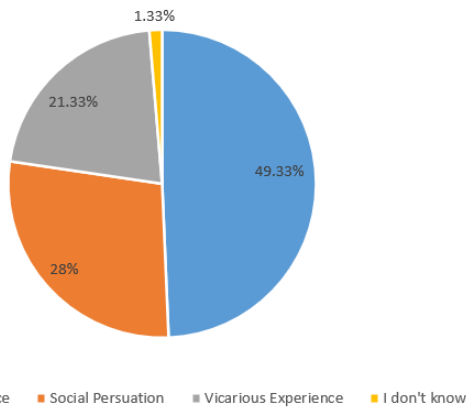


Figure 2.4(e): Distribution of predicted categories for Question#1

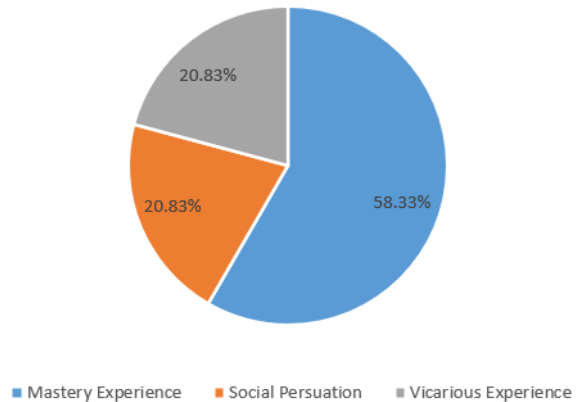


Figure 2.4(f): Distribution of predicted categories for Question #2

Below in Table 2.4(a) is an example of the question asked and the output of ChatGPT’s predicted category and rationale for choosing the predicted values based on Bandura’s research and framework.

Question#1: If you stayed in an engineering or computer science major, what or who influenced your decision to continue?

Table 2.4(a): ChatGPT Output of Predicted Category and Rationale

<u>Student Response</u>	<u>Predicted Category</u>	<u>Reason/Source of Truth</u>
Passion	Mastery Experience	The physiological response to content and the voiced belief in the enjoyment of the subject suggest influence from internal sources such as personal interests or previous successes, indicating mastery experience.
A larger field of work for future work opportunities	Vicarious Experience	The consideration of future work opportunities suggests influence from observing the outcomes and experiences of others in similar situations, indicating vicarious experience.
Academic validation and knowing that no matter how many tries to pass a class, I will do it	Mastery Experience	The voiced belief in the ability to overcome academic challenges suggests influence from internal sources such as personal beliefs or previous successes, indicating mastery experience.
Being far into the semester and not knowing what else I would do	Vicarious Experience	The consideration of being far into the semester suggests influence from observing the experiences and decisions of others in similar situations, indicating vicarious experience.
Commitments, family members I look up to	Social Persuasion	The influence of family commitments suggests social persuasion as the source of influence.

Table 2.4(a): ChatGPT Output of Predicted Category and Rationale

<u>Student Response</u>	<u>Predicted Category</u>	<u>Reason/Source of Truth</u>
Engineering is kind of cool and I can see myself enjoying a career path that relates to engineering where I get to create or study cool devices	Mastery Experience	The expressed interest in engineering and envisioning a fulfilling career suggest influence from internal sources such as personal interests or previous successes, indicating mastery experience.
Family	Social Persuasion	The influence of family suggests social persuasion as the source of influence.

As stated above, these values were then compared with the developed taxonomy and researcher assigned values for Question 1 resulting in only a 9.33% difference. For Question 2, this comparison resulted in only an 8.33%. An example of the comparison between the AI predicted categories based on Bandura’s research and the predicted category as rated by the researchers while utilizing the developed taxonomy is shown below in Table 2.4(b).

Question#1: If you stayed in an engineering or computer science major, what or who influenced your decision to continue?

Table 2.4(b): Table 2.4(b): Predicted Category Utilizing Bandura vs Bandura and Taxonomy

<u>Student Response</u>	<u>Predicted Category (Using Bandura's Paper)</u>	<u>Predicted Category (Using Developed Taxonomy)</u>
Passion	Mastery Experience	Mastery Experience
A larger field of work for future work opportunities	Vicarious Experience	Vicarious Experience
Academic validation and knowing that no matter how many tries to pass a class, I will do it	Mastery Experience	Mastery Experience
Being far into the semester and not knowing what else I would do	Vicarious Experience	Vicarious Experience
Commitments, family members I look up to	Social Persuasion	Social Persuasion
Engineering is kind of cool and I can see myself enjoying a career path that relates to engineering where I get to create or study cool devices	Mastery Experience	Mastery Experience
Family	Social Persuasion	Social Persuasion

The results of the study generate confidence in the researchers for both the taxonomy development and application as well as the use of AI to effectively and efficiently analyze large samples of qualitative research data when primed with an existing theoretical framework, such as that of Bandura’s.

3 | Validity, Reliability and Limitations

At the heart of validity and reliability is transparency and clarity. Walther et al. [39] present a typology of quality strategies recognized by the engineering education research community. A selection from this typology is applicable to the data collection and analysis phases of this study. These include theoretical validation, procedural validation, communicative validation, pragmatic validation, and process reliability. These methods work in combination to align the study to a theoretical process, promote communication throughout the study, maintain consistency, and manage researcher bias while allowing for unique contributions.

Data analysis used coding methods described by Saldaña [51], in combination with analysis recommendations from Savin-Baden et al. [52] and the phenomenographic research community [54], [55], [56]. Selecting the domain analysis process aligned with taxonomy use and providing clear instruction to ChatGPT for its role in this project. Regular communication with research team members supported member checking and triangulation of results employed to strengthen validity [57]. All members of this project have an affiliation with the college making this study relevant to their experience, increasing the desire to use this work to increase retention and persistence in engineering and computer science. Finally, aligning with advice from Åkerlind et al. [54] to establish a clear, reliable process. This study used a modest data set, domain analysis with a taxonomy designed specifically for the project, and a dynamic research team with a clear understanding of the project.

Several limiting factors were present in this study. The most significant was the use of ChatGPT as a research team member. Artificial intelligence is a new and largely questioned as an acceptable or reliable tool. The research team included a skilled computer science researcher familiar with how to provide coded instruction to ensure reliable outcomes. This in combination with a member checking process shown in Figures 2.4(c) and 2.4(d) managed for this limitation.

4 | Discussion and Future Work

This work accomplished several objectives. First, it presented the contextual nature of student development, and a robust literature base informing this work. Characteristics of academic research silos are common and make sense give the unique language patterns disciplines develop. For example, physiological affect are the emotional responses an individual has as they engage with their environment. Sentiment analysis seeks to help computer scientists understand emotional tones in large volumes of text. Systems engineers make sense of complex content using signs to provide instruction and clear communication for interpreting data. The combination of research disciplines, language, and tools provided a control method for physiological affect. We know students are influenced by emotions and feelings. This study shows how to interpret their effect on tangible SE sources: mastery experience, social persuasion, and vicarious experience. More cross discipline research collaborations using complex models are needed. These efforts may be the key to moving the needle ahead on student retention in engineering and computer science.

Second, with careful software engineering, artificial intelligence (AI) tools such as ChatGPT can contribute as a member of a research team. Key approaches to the use of AI in this manner

include ensuring ChatGPT knows the theoretical base it will use. Once this is established, providing context to guide interpretation, such as through a taxonomy, is important to generating reliable data analysis.

Finally, mastery experience was shown to be an important element of student perception in their ability to repeatedly engage with challenging material which is consistent with the literature. However, using a taxonomy and filtering student statements through a physiological affect lens showed an increase in the influence of social persuasion and a decrease in mastery experience for students continuing in their major. This study used a small data set to test this approach. Application on a larger data set is needed to demonstrate its viability and determine if this SE source distribution remains consistent.

This work shows the nature of internal processes influencing external behaviors which are presented as repeatedly engaging with challenging engineering and computer science content. A full understanding of the student experience is important to creating retention programs that meet their needs. Turning to math, engineering, and science to solve the retention problem makes sense. However, it is important to remember logic can be applied to the laws of human behavior if the ability to be flexible remains.

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