# Exploratory Literature Review of Education Theories Guiding Engineering and Physics Outreach

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## Abstract

Due to the increasing demand for a diverse, STEM-competent workforce, many universities are participating in engineering and physics outreach activities for K-12 students. Despite the proliferation of these outreach programs, the fundamental learning and social theories that guide development of high-impact outreach experiences can be unclear, hindering their transferability. The purpose of this literature review was to identify, categorize, and compare pedagogical theories and frameworks behind university-driven, K-12 engineering and physics outreach programs. This review can act as a guide to future outreach initiative development, implementation, and assessment, especially for new faculty who may feel overwhelmed by the number and breadth of outreach programs to review.

Using our institution's library discovery service, 216 articles with the subjects containing outreach, AND engineer* OR physics, AND theor* OR framework OR model, were screened. In reviewing these articles, a great number of articles were found that described what was done in an outreach program; fewer described why fundamentally things were done that particular way. Using the screening criteria of university-driven K-12 physics or engineering informal education, we included 37 articles in this review that presented a theoretical basis or framework for developing or assessing engineering or physics outreach programs. The theories were separated into five predominant learning theories: cognitivism, constructivism, contextualism, experientialism, and humanism. In addition to an overarching learning theory, all articles also indicated other frameworks that shaped the lens through which they considered the outreach activities.

This review article introduces and compares learning theories that universities are currently using to design, implement, and assess outreach activities, as well as highlights which theories may be most aligned with specific outreach goals. Ultimately, the varied learning, social, and logical models being used to shape engineering and physics outreach which can aid in program transferability are showcased along with how pedagogical theories can advance the goals of engineering and physics outreach programs.


## Introduction

Motivated by a desire to introduce new solvers into the world, there is a national push to increase the number of students pursuing and obtaining science, technology, engineering, and mathematic degrees. University-driven outreach to preschool through 12th grade students is one way to encourage this next generation. Outreach programs exist from single day events [1] to week long summer camps, to more continuous STEM clubs [2]. Many outreach programs are designed specifically to generate excitement about science, engineering, and technology careers [3], [4]; others desire to promote specific scientific literacy [5], [6]. To address the disparity of women and underrepresented minorities in engineering and physics, some outreach programs are aimed at increasing diversity of, inclusion in, and access to the scientific community [7], [8]. These outreach programs may seek to shift perspectives on who an engineer or physicist is, provide role models for underrepresented minorities, or present engineering in a way that resonates with the target audience.

Given that the motivations for pursing outreach activities are varied, so to must the educational theories used to develop, implement, and assess outreach vary. Each outreach team must answer for themselves, why are we doing outreach and what will students gain from participating? With that why and what in mind, outreach teams can consider what learning theories, organizational models, or supporting frameworks are best for achieving that goal. But how can new outreach teams wade into the outreach literature to identify the best starting place without becoming overwhelmed? Our team seeks to present this exploratory systematic review as a primer for those desiring to begin meaningful new outreach programs that build on the guiding theoretical basis of others.

Indeed, the breadth of past and ongoing outreach activities in engineering and physics call for systematic reviews and meta-analysis of existing outreach literature to both understand what has been done and what remains to be done. Borrego and coworkers have suggested that within engineering education, "More reviews of prior work conducted more systematically would help advance the field by lowering the barrier for both researchers and practitioners to access the literature, enabling more objective critique of past efforts, identifying gaps, and proposing new directions for research.[9]" This review provides these benefits to new educator and researchers seeking to develop, implement, or asses university to K-12 engineering and physics outreach. This review was guided by the following research questions: RQ1: What learning theories and frameworks are being used to develop, implement, and asses engineering and physics outreach activities? RQ2: Do these learning theories support specific goals of engineering and physics outreach? A concept map of the paper is shown in

Figure *1*, indicating the structure of this review articles. In the sections that follow we will discuss the overarching learning theories found to be guiding engineering and physics outreach, describe in detail some of the specific frameworks, activities, and topics used to structure university driven K-12 outreach, and then point out connections between outreach goals and theories and frameworks.

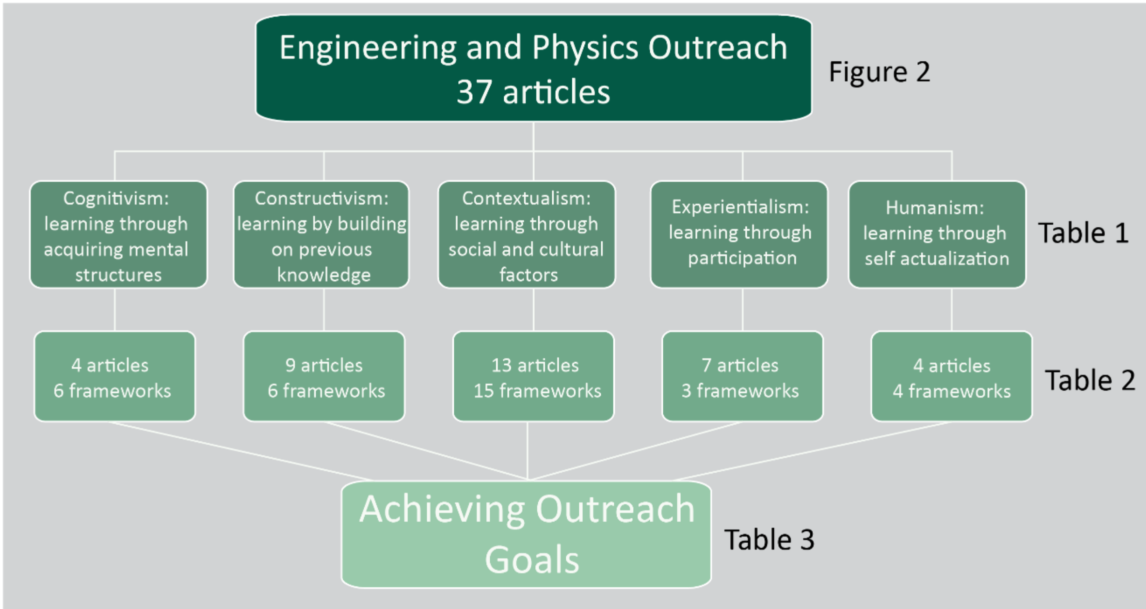


Figure 1: Concept map for this exploratory literature review of the pedagogical theories guiding engineering and physics outreach indicating where information can be located.

## Methods

### Positionality

As is especially informative in qualitative research, it is helpful to understand our positionality and, therefore, the lens through which we analyzed the literature found in this review. The first author is a white, female U.S.- born engineer with experience in product development and expertise in the field of materials science and engineering. She is a developing engineering education and formation researcher currently teaching within a Physics, Engineering, and Astronomy department. The second author is a white, U.S.-born male pursuing his bachelor's in engineering physics. He participated in a state funded STEM outreach program during his time in high school. The third author is a white, female U.S.-born scholar with expertise in educational psychology and empathy research.

### Search Strategy

Our procedure structure was based on the guidance provided in Systematic Literature Reviews in Engineering Education and Other Developing Interdisciplinary Fields [9]. Following the authors recommendation, we consulted with a librarian to develop our search protocol. We used our institution's library discovery service, which searches all 322 of our library's database subscriptions. We searched for articles with subjects containing outreach, AND engineer* OR physics, AND theor* OR framework OR model. The wildcard (*) was used to capture variations of theory, theoretical, and engineer, engineering, etc. The variety of words related to theories was used after some initial broad searches showed that each of these words may be used to describe the theorical grounding for engineering outreach activities. While the use of the word "STEM" may have drawn additional articles, this review seeks to focus on engineering and physics specific outreach due to the first author's positionality within a Physics, Engineering, and Astronomy department. Future research with multidisciplinary collaborators could explore STEM outreach theories more broadly.

## Selection and Inclusion Criteria

Our identification, screening, and inclusion process is shown in the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) of Figure 2. Our search resulted in 216 articles that matched our keywords. From these, 26 articles were removed as duplicate, non-English, or non-peer reviewed news articles. Based off of title, 44 articles were removed from inclusion due to lack of any element related to the current study, i.e. not related to engineering, physics, or outreach. This resulted in 146 abstracts being review, with 74 abstracts not meeting the inclusion criteria of related to University to K-12 outreach and not related to engineering or physics. The full texts of 72 articles were reviewed to determine if the articles provided a theory, framework, or model that was key in the development, implementation, or assessment of the outreach activity. Of these 72, 30 did not contain such a theory, framework, or model, four were not university driven outreach activities, and 1 full text could not be obtained. The 37 articles remaining passed on to the synthesis and analysis phase.

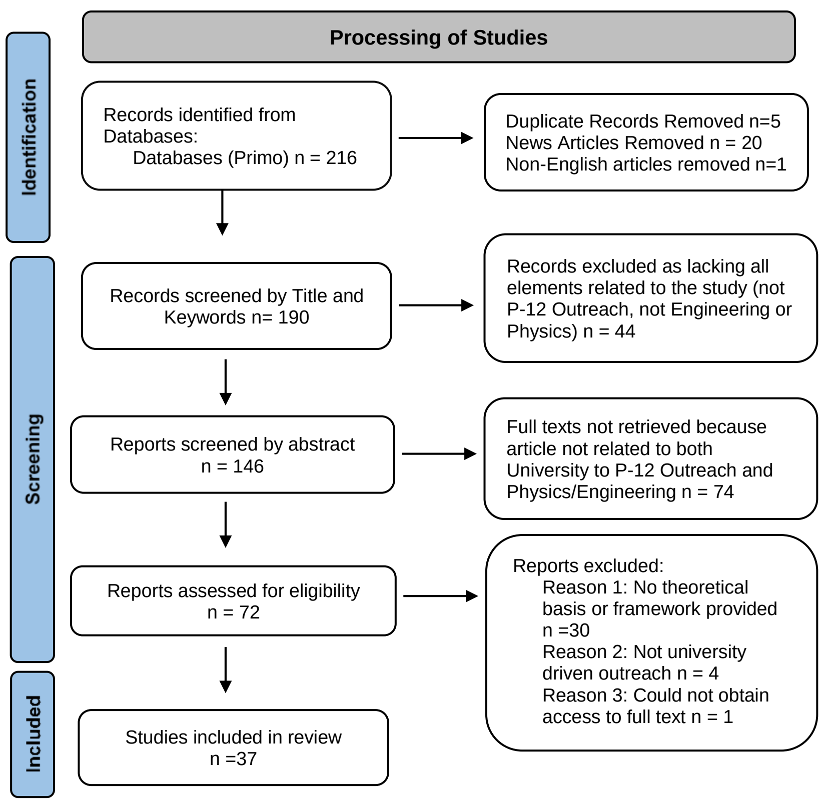


Figure 2. PRISMA showing the identification, screening, and selection process for this systematic review.

## Analysis and Synthesis

To address RQ1, the theory and framework or model central to an article was noted. After reviewing several articles with a wide range of models or frameworks the authors began to identify broad theoretical groundings of well researched learning theories to help categorize each article. Some of the overarching theories were not clearly stated in each of the articles, but instead a model or framework was used exclusively. If a learning theory was not mentioned explicitly, the model or framework cited in the paper was considered to determine the most applicable learning theory. Each of the general theory categories represent well-researched learning theories throughout the field of Educational Psychology and defined in Table 1.

## Limitations

While we developed and enacted our procedure to follow best practices in engineering education systematic literature reviews, we acknowledge relevant studies may still be missing from our synthesis. As our intension was to focus on engineering and physics outreach, we inevitably missed articles addressing engineering and physics through the acronym of STEM. While we expect the number of studies missing due to these two limitations to be small, it must be noted that the study does not include articles published after September 2023, as this is when we began the synthesis process and does not contain articles in journals to which our library does not subscribe and therefore we do not have access. Additionally, while beyond the scope of this article, each of the five overarching educational psychology theories identified within the university-driven K-12 outreach literature could be used as keywords in future more specific literature reviews on the use of these theories in engineering education generally.

## Results and Discussion:

## Overview of Theories

From the 37 articles included in this review, we found 5 predominant learning theories provided guidance for the design, implementation, and/or assessment K-12 outreach. These learning theories are listed in Table 1 along with an overview of the theory and a reference that provides a more in-depth consideration of the theory. The five theories were cognitivism, constructivism, contextualism, experientialism, and humanism. Four of the 37 articles foundational theory was cognitivism. This theory is primarily concerned with "what goes on inside people as they learn from and respond to their environment" [10]. Nine articles used constructivism as their theoretical basis. Constructivism is the "theoretical perspective proposing that learners actively construct [rather than passively absorb] knowledge and beliefs from their experiences' [10]. The largest theoretical underpinning used was contextualism with 13 of the 37 articles reviewed. Contextual theory "focuses on how people's general physical, social, and/or cultural surroundings support their learning, development, and behavior" [10]. The fourth theory utilized in the outreach methodology was experientialism with seven articles using this theoretical foundation. Experientialism can include constructivist techniques, but it is set a part by not just the "doing", but also the reflecting on the experience in real-life situations. One of the original experientialist, Kolb [11] used a four-stage learning cycle of concrete experience, reflective observation of the new experience, abstract conceptualization, and active experimentation. Humanism was the fifth theory utilized, guiding four of the articles reviewed. Humanism can be applied through constructivist and cognitive means but is differentiated by its unique human-centered focus. Humanism looks at "human freedom and dignity to achieve full potential" and uses self-direction to "accomplish self-actualization, self-fulfillment, self-motivation values, goals, and independence in their learning" [12]. The theories observed in the articles reviewed are appropriate for outreach design studies and narrow down the research lens for future studies.

Table 1: List of learning theories found in university-driven outreach articles with brief overview of key idea.

| General Theory | Overview | Connection to Outreach |
| --- | --- | --- |
| **Cognitivism** | "Stress the acquisition of knowledge and skills, the formation of mental structures, and the processing of information and beliefs." [13] | Outreach participants develop mental capacity and consider their systems of beliefs. |
| **Constructivism** | Learning occurs through an active process of constructing meaning through connecting new knowledge to what one already knows. "Emphasis on identifying prerequisite relationships of content."[14] | Outreach participants build their own knowledge, often through connections to previous knowledge and solving problems. |
| **Contextualism** | "Highlight the roles played by social and cultural factors"[13]. Contextual theories also "emphasize the ongoing and pervasive influences of learners' general physical, social, and cultural environments on thinking and learning" [10]. | Outreach activities consider learners' specific perspectives when developing and assessing programs. |
| **Experientialism** | In experiential learning, students actively engage through participation, analysis, synthesis, and reflection to increase knowledge, develop skills, and clarify values. [15] | Outreach participants learn through doing/performing activities related to real word applications. |
| **Humanism** | "Addresses people's capabilities and potentialities as they make choices and seek control over their lives" [13]. | Outreach participants are considered as whole persons, encompassing identity, feelings, and motivations. |

## Review of Outreach Articles

The articles included in this review can be seen in Table 2, which lists the titles, guiding learning theory, specific frameworks used in development, implementation, and/or assessment of the outreach program, and the target audience of the outreach program. In the following discussion, articles are grouped by the guiding general learning theory. Articles were found with target audiences encompassing all age groups in K-12, however no preschool outreach activities were found. All guiding learning theories were used by at least one outreach team seeking to reach elementary, middle, and/or high school students, except for Humanism which guided outreach only for high school students in the articles reviewed. Additionally, all learning theories were used by at least one outreach team seeking to specifically reach underrepresented communities (URC) in physics and engineering. While this points to the universality of these learning theories, when paired with sub-theories and organizational frameworks, specific learning theories are most appropriate for specific outreach goals, as discussed in the implications for future outreach section.

Table 2: Overview of article included in this review outlining the relevant learning theory, specific frameworks used, and target outreach audience.

| Title | General Theory | Specific Frameworks | Outreach Audience |
|---|---|---|---|
| Exploring the Impact of University Engineering Role Models on Elementary Students [16] | Cognitivism | Social Cognitive theory | 3rd-6th Grade Students |
| Promoting Gender Equity in Engineering: An Exploration of Female Pre & Post-Secondary Participant Perceptions & Experiences in QSEA [17] | Cognitivism | Gender Schema Theory | Former Female Summer Students Ages 14-20 |
| Evaluation of the Alaska Native Science & Engineering Program (ANSEP). Research Report [18] | Cognitivism | Logic Model, Theory of Change | URC and All Middle School Students |
| The Impact of STEM Experiences on Student Self-Efficacy in Computational Thinking [19] | Cognitivism | Cognitive Load Theory, Social Cognitive Theory, Service Learning | 5-9th Grade Students |
| The Evaluation Of A Comprehensive Middle School Outreach Program The Strategy, The Results, And The Challenges [20] | Constructivism | Logic Model, Problem-based learning | Middle School Students |
| Evaluating A Comprehensive Middle School Outreach Program—The Results [21] | Constructivism | Logic Model, Problem-based learning | Middle School Students |
| Systems Thinking in Science Education and Outreach toward a Sustainable Future [22] | Constructivism | Problem Based Learning, Service Learning | General K-12 |
| Using Technology Based Experiences To Connect Engineering Design, Science, And Mathematics For Secondary School Teachers [23] | Constructivism | Project Based Learning, Authentic and Situated learning | K-12 Math Teachers |
| Integrating mechatronics in project-based learning of Malaysian high school students and teachers [24] | Constructivism | Project Based Learning | Malaysian High School Students and Teachers |
| Teaching Magnetoelectric Sensing to Secondary School Students—Considerations for Educational STEM Outreach [6] | Constructivism | Design Based Learning | German Students Aged 15 and Older |
| Beyond 'chalk and talk': educator perspectives on design immersion programs for rural and regional schools [25] | Constructivism | Design Based Learning | Australian High School Students and Teachers |
| NGSS Engineering Practices in Physics Instruction: Building a Night Light [26] | Constructivism | Design Based Learning | High School Students and Science Teachers |
| Can Grade-6 Students Understand Quarks? Probing Acceptance of the Subatomic Structure of Matter with 12-Year-Olds [5] | Constructivism | Content Focused Curriculum Development | 6th Grade Swiss Students |
| Characterizing Pedagogical Practices of University Physics Students in Informal Learning Environments [27] | Contextualism | Sociocultural Theory, Historical Activity Theory | K-8 Students |
| Universities conducting STEM outreach: A conceptual framework [28] | Contextualism | Theory of Legitimacy | General K-12 |
| Using a Campus-wide Community of Practice to Support K-12 Engineering Outreach [29] | Contextualism | Logic Model | General K-12 |
| University/Industry Led Transportation Focused Weekend Outreach Programs for 7th-12th Grade Girls: A Context Focused Framework [30] | Contextualism | Context Focused Curriculum Development | Female 7- 12th Grade Students |
| A Model Project to Improve the Climate for Women in Engineering [8] | Contextualism | Cooperative Learning Model | Female K-12 Students |

| | | | |
|---|---|---|---|
| Enriching Undergraduate Experiences with Outreach in School STEM Clubs [2] | Contextualism | Sociocultural Theory, Situated Learning, Participation Metaphor | Middle and High School STEM clubs |
| Outreach and Identity Development: New Perspectives on College Student Persistence [31] | Contextualism | Sociocultural Theory, Weidman Socialization Framework | High School Students |
| The Impact of a University-Based School Science Outreach Program on Graduate Student Participants' Career Paths and Professional Socialization [32] | Contextualism | Weidman Socialization Framework | General K-12 |
| A framework for developing community-focused medical physics outreach programs [33] | Contextualism | Sociocultural Theory, Community-Focused Framework | URC K-12 Students |
| Characterizing engineering outreach educators' talk moves: An exploratory framework [34] | Contextualism | Sociocultural Theory, Situated Perspective | 4- 5th Grade Students |
| Refining a Model for Understanding and Characterizing Instructor Pedagogy in Informal Physics Learning Environments [35] | Contextualism | Cultural-Historical Activity Theory | 4- 12th Grade Students, 50% URC |
| Creating a Physicist: The Impact of Informal Programs on University Student Development [36] | Contextualism | Situated Learning, Transformative Learning Theory, Role Identity | General K-12 |
| Outreach at Scale: Developing a Logic Model to Explore the Organizational Components of the Summer Engineering Experience for Kids Program [37] | Contextualism | Logic Model, Collective Impact Framework, Community-Focused Framework | URC 3rd - 5th Grade Students |
| Combining Mentoring and Service Learning - A New Approach [7] | Experientialism | Service Learning | K-8th Females |
| Use of kite-based measurement systems for service-learning in informal settings [38] | Experientialism | Service Learning | 9th Grade Students |
| Kidslearn In Introduction To Engineering Design [4] | Experientialism | Service Learning | 4- 8th Grade Students |
| Using Service Learning To Integrate K 12 Outreach Into A First Year Engineering Program [3] | Experientialism | Service Learning | High School Students |
| The Search for Exoplanets: A Capstone Project in Service Learning and Outreach [39] | Experientialism | Service Learning | 6- 12th Grade Students |
| Building Engineers and Mentors: A Model for Student-Led Engineering Outreach [40] | Experientialism | Service Learning | K-8th Grade Students |
| The Effects Of Stomp On Students' Understandings Of And Attitudes Toward The Engineering Design Process [41] | Experientialism | Service Learning, Situated Learning, Pedagogies of Engagement | General K-12 |
| Promoting Neurodiversity in Engineering Through Specialized Outreach Activities for Pre-college Students [42] | Humanism | Positive Psychology Theory | High School Students with ADHD |
| Engineering Students as Science Teachers: A Case Study on Students' Motivation [43] | Humanism | Motivation Theory, Self-determination Theory | 8-12th Grade Students |
| Physical Science Day: Design, Implementation, and Assessment [1] | Humanism | Motivation Theory, Expectancy-Value Theory | High School Students, Hispanic Students |
| Physics Career Education Day: Design, Implementation, and Assessment [44] | Humanism | Motivation Theory, Expectancy-Value Theory | High School Students, Hispanic Students |

Cognitivism Articles:

Within the broad learning theory of Cognitivism, four articles were found that used specific cognitive theories to guide the development, implementation, and/or assessment of K-12 outreach. In cognitive load theory, a sub-theory of Cognitivism, effective instructional design considers the limitations of a learner's working memory capacity [45]. A learner's total working memory capacity consists of germane load, extraneous load, intrinsic load, which make up total cognitive load, and free capacity. Instructional design can impact germane and extraneous load, which can free working memory to allow for greater intrinsic load of the content to be learned [45]. Cognitive load theory was used in the development of computational thinking and computer science outreach activities by Weese and coworkers [19]. In development of their outreach activities, the authors reduced the cognitive load on participants by using block-based programing and creation of sub-goals. Engineering and physics concepts have large intrinsic load associated with them, therefore designing outreach that reduces extraneous load is important for facilitating learning.

As Cognitivism emphasis mental structures and process, outreach programs guided by cognitivism may use logic models to visualize each step of an outreach program, beginning from necessary inputs to the long-term effects caused by the activities. The logic model breaks an outreach program down into individual sections and outlines what is needed for the operation and evaluation of each section. The Alaskan Native Science & Engineering Program, ANSEP, developed a logic model to visualize their adaptation of the cognitivism theory, and the theory of change to approach STEM outreach [18]. They describe the necessary inputs for mentoring students from middle school onward and providing resources for students to succeed through graduate school. This program was targeted towards URC but was nondiscriminatory towards other student populations [18]. Logic models for outreach programs can be paired with other guiding learning theories such as constructivism and contextualism to both support the current outreach organization and facilitate the transferability of outreach activities to other settings, as will be discussed in the respective sections.

In the dissertation by Joseph [17], the cognitive theory of gender schema theory provided the conceptual framework for assessing an outreach program's impact on female participants. Here, the processing of beliefs, a specific concern of cognitivism, regarding gender stereotypes of engineering was studied, finding that female outreach participants were able to form "positive perception of the roles of females in engineering"[17]. The female participants desired to understand more fully the female experience in engineering and wanted greater female representation in the outreach programs in which they participated. In the article by Portsmore and coworkers [46], another social cognitive theory, social identity theory, was used to develop a survey to measure engineering identity and interest in elementary students. Both studies show how educational and psychology theories can be used in the assessment of outreach outcomes related to beliefs about outreach participant's future and belonging in engineering. These articles highlight the role representation may play on participants' cognitive constructs of who engineers and physicists are.

Constructivism Articles:

Nine articles were found that connected to the learning theory of Constructivism. Constructivist theory espouses that knowledge is individually created through active mental steps connecting new knowledge to prior knowledge [14]. Compared to Cognitivism, Constructivism places greater emphasis on learning individual's creation of knowledge, which fits well with frameworks such as project- and design-based learning where learners may create their own solutions. In project-based learning, learners pursue knowledge independently or in teams through instructor facilitated, but student-driven, inquiry usually addressing real world problems [47]. In the study by Tauro *et. al.* [24], educators from the New York University School of Engineering implemented an outreach program with the National University of Malaysia aimed at encouraging Malaysian high-school students to pursue engineering and scientific careers. The authors used the context of creating smart cities to guide learners in their pursuit of power generation and storage solutions. Malaysian stakeholders provided positive feedback, and post-testing of participants showed an increased interest in pursuing engineering careers. The study by English *et. al.* [23] sought to connect the theoretical to the practical by providing authentic learning experiences on virtual design and designing for earthquakes to secondary school teachers. The authors also used situated learning theory, which states that both an authentic context and collaboration are required for learning, to guide the development of their outreach activities [23].

Project based learning and design as a pedagogical framework both emphasize aspects of practicing engineers work. As one of the goals of outreach is to encourage students to pursue careers in engineering, it is logical that these important aspects of engineering work are being used as frameworks for outreach. Three articles in this review describe using design-based learning activities guided by Constructivist theory to facilitate outreach activities. In one, students built magnetic field sensors [6], in another a night lights [26]. The outreach described by Wright and coworkers [25], which provided place-based design experiences to rurally located students and teachers, was guided by the social constructivist learning paradigm. This sub-theory of constructivism indicates that meaning making occurs as learners build knowledge, aided by instructor scaffolding, through the lens of their specific cultural context and social interactions [48].

In addition to the guiding learning theory, successful large-scale outreach requires the coordination of university resources, which must also be considered during outreach development. The Office of Naval Research funded the Virginia Demonstration Project (VDP) which used constructivism theory and a problem-based learning framework to approach STEM outreach [20], [21]. The VDP outreach program was implemented in three school districts, which had disparately been affected by federal funding cuts [21]. The implementors of the VDP used a logic model to provide clarity on the program structure and outcomes, which provides clarity for others seeking to implement similar large scale programs [20].

Contextualism Articles:

The 13 articles guided by Contextualism used a variety of frameworks to conduct their research. In fact, 6 different frameworks were found, and each study used the frameworks in a variety of ways. For the sake of concise discussion, studies have been grouped together, but each study functions within its own unique framework. The categorized frameworks used are community-focused, situated learning, cultural-historical activity, socialization, context focused curriculum development, and theory of legitimacy.

Four articles were identified as using a community-focused framework. Within each of the articles, however, additional frameworks were utilized, as will be discussed. Santoso, Jupitz, and Lin [33] looked specifically at medical physics to create a community-focused outreach program designed for URC. The study's purpose was to explain the racial and ethnic diversity problem within medical physics and to reach K-12 URC students and families through relationship building. Through 42 events and 1,907 participants over a four-year period, the study found that the community-focused outreach was effective at introducing and inspiring URC K-12 students to pursue careers in STEM. The National Society of Black Engineer's Summer Engineering Experience for Kids (SEEK) was another community-based program which implemented principles from Contextualism [37]. By combining a collective impact framework with a logic model, the SEEK program provides detailed organizational strategies for other outreach programs seeking to reach URCs. The National Science Foundation funded a campus wide project at North Carolina State University, which also used a collaborative impact framework and a logic model [29]. Here, individual outreach programs were able to evaluate their goals and align with overall university outreach objectives because of the comprehensive organizational structure and clarity of guiding educational theories. The fourth study was a large 3-year pilot project focused on K-12 educators and girls to create awareness of engineering and technology [30]. The authors believed improving classroom climates through teacher training and providing students with female engineer role models would improve recruitment and retention of females in the STEM pipeline. This study showcased collaborative or corroborative learning within the gender focused context of a female community.

The next three articles guided by Contextualism primarily used the framework of situated learning, but all three used additional frameworks to support and assess the outreach activities. Situated learning involves immersing learners in environments that provide opportunities to form new knowledge though the combination of past experience and present observation [48]. Ferrara and colleagues [2] utilized undergraduate STEM majors to organize middle and high school in-school and after-school clubs and teams. In addition to situated learning, this study also used communities of practice and sociocultural theories to provide authentic learning opportunities for both the undergraduate and K-12 students. Sociocultural theories seek to explain "how culture influences human development" [49]. The authors found that their study highlighted the importance of collaboration, the need for discipline specific knowledge, and the need to persevere through challenges in STEM education. Rethman et. al. [36] also used undergraduate physics students, investigating five informal outreach programs that focused on situated learning, transformative learning, and dynamic systems model of role identity. These different outreach programs where designed to help the undergraduate students find their physics identity, build a sense of community, skill development, and motivation. Through the lens of not only contextualism, but also these additional three frameworks, the study found that students reported that the outreach programs had a strong impact on recognizing connections between physics topics, an overall better understanding of physics, and teamwork and networking skills. Miel et. al. [34] also used situated perspective and sociocultural frameworks to look at engineering outreach educators' discourse, identify talking moves that support student participation, and beginning conversations about ambitious engineering teaching. This was a formative study that found that outreach educators, with support, can engage in ambitious teaching which can turn to ambitious learning.

Two articles used contextualism as the foundational learning theory paired with sociocultural historical activity frameworks, which uses higher order cognition through language and other cognitive tools to engage in the world and learn through cultural [50]. Hinko et. al. [27] utilized physics undergraduate, graduate, and postdoctoral students to work as educators in K-8 afterschool programs over the course of a semester. The cultural historical activity framework was used to examine how the university educators interacted with the K-8 students while they participated in hands-on physics activities. Three primary modes of pedagogical interaction were found: instruction mode, consultation mode, and participation mode. By observing and continuing to evaluate these instructional modes, the authors believe that outreach teaching can improve, and outreach program will increase students' interest in physics. The second study that used sociocultural historical activity as their framework modeled their study off of the above 2016 study and produced three primary results from their expanded study [35]. The study substantiated the 2016 findings of the three pedagogical modes; it also expanded on teacher preparation, and refined the three modes into a new modal taxonomy that consists of content learning, engaged exploration, and efficient operations. The three original modes (instruction, consultation, participation) are incorporated into this new taxonomy with the addition of a combined instruction/participation, instruction/consultation, and consultation/participation modes. This expanded model hopes to increase the ability to assist university educators in finding better pedagogical methods of instruction, especially for K-12 outreach.

Two articles used socialization as the framework within Contextual theory. Bergerson et. al. [31] used socialization to examine how engaging in high school outreach programs increased undergraduate engineering students' enrollment and persistence, as well as, helped engineering students develop an engineering identity. The study found that undergraduate students who participated in the outreach program connected better with faculty, to real world concepts and peers, and began to see themselves as engineers. Using the socialization framework, as engineering students engaged more with faculty, taught high school students within in STEM, and developed relationships, student's persistence increased and they created a stronger connection to the field itself. Laursen et. al. [32] also used socialization framework in a similar study but focused on STEM graduate students who participated in a K-12 outreach program, Science Squad, from 1992-2002 to look at how these graduate students' participation impacted their career trajectories. Through interviews of 34 STEM graduate students four primary categories emerged in light of a gain in socialization (teaching, communication, and management skills; understanding issues related to education and social context; personal development; and career skills) [32]. The study found that graduate students that participated in Science Squad were more likely to be science educators due to the specialized socialization received.

The last two articles that utilized Contextual Theory used two different frameworks that could not be grouped with any of the other articles in this theoretical category. Fields et. al. [30] used a transportation context-focused curriculum design framework to develop creative, hands-on activities geared at girls in grades 11-12 in a weekend outreach STEM event called "Reaching the Sky". The curriculum wanted to relate to the girls daily lives and show social relevance. The program used an all-female team of both higher education educators and science, engineering, and mathematics undergraduate students to create and implement a variety of activities. The study found that after the outreach program participants left with additional knowledge of STEM fields and were more likely to pursue a STEM career based on questionnaires that the participants took upon completion of the weekend event. By focusing on a primary context and developing the curriculum around it the study was successful in achieving their desired results. The final study noted to use Contextual theory varies considerably from all of the other studies. The theory of legitimacy framework was used to consider how universities approach outreach in STEM. The framework looked at "top-down" initiatives controlled by university governance (internal) versus "bottom-up" controlled by individuals, departments, or colleges without university governance support (external) [28]. The study looked at two different countries, Australia and Israel. Australia is more likely to use the bottom-up approach and Israel is more likely to the use the top-down approach. The study found that Israel was more successful due to the university buy in which creates more "legitimate" outreach programs for stakeholders in general. This study is unique in that it compared two different countries and was not looking at any one time of outreach program. Instead the study wanted to find which support system was more successful in creating outreach programs in two different contexts.

Experientialism Articles:

All of the articles within the experientialism category used the specific framework of service learning to develop and implement their outreach activities. Service Learning provides a learning environment in which learners gain agency to address the needs of others while developing skills, competencies, and belonging in their desired communities [51]. It is noteworthy that one of the fathers of experientialism is Carl Rogers, who was also one of the first to study empathy in a therapeutic setting [52], as empathy, understanding, feeling, and acting on the perspectives of others, is embedded in the ideals of service learning.

The seven experientialism articles considered undergraduate engineering and physics students' learning *through* development of and participation in K-12 outreach. Three of these articles were directed at first year engineering students [3], [4], [38]. In the article by Thomas and Oaks [3], service learning provided a context for first-year engineering students to engage with high school students on science and engineering projects related to energy and design. The engineering students were a part of learning communities that require a service learning component, which the outreach activities provided. The article by Ocif and coworkers [7] also considered outreach as service learning for groups of female undergraduates, as gender inclusion was the motivator for development of their outreach activities. In the article by Almaguer and coworkers [40], a student network and associated class was formed to create, implement, and assess outreach. One goal of their outreach was to change perceptions of how engineers and scientists "look", which they assessed through asking students to "draw an engineer" before and after participating in the outreach activities. In the article by Carberry *et. al.* [41], the authors propose that participation in K-12 outreach can aid engineering students in their understanding of engineering concepts and skills, an idea that aligns with the theory of experimentalism.

All of the articles related to engineering outreach created student communities to address the local community need for informal engineering education, while providing students with a sense of belonging. Collectively, these articles show a desire that engineering students notice and demonstrate the orientation of the engineering discipline towards the betterment of society. In contrast, the article by Archer *et. al.* [39] describes how service learning can be applied to an individual physics capstone project aimed at creating a computer simulation to introduce $6^{th}$ -$12^{th}$ grade students to exoplanets and their discovery. While the disciple of physics does not have the explicit orientation towards society betterment as called out for engineers in the National Society of Profession Engineers Code of Ethics [53], many physics organization encourage community service.

Humanism Articles:

Out of the four articles found to use the Humanism theory, one used positive psychology theoretical framework [42], one used a motivation with self-determination framework [43], and two used the identical expectancy value framework along with motivation to orientate their studies [1], [44]. The study using positive psychology as their framework involved two different pilot studies. The first was a two-week summer engineering program involving five high-school students (aged 14-18) who had been diagnosed with ADHD and the second pilot program included 10 middle grades students (aged 10-13) also diagnosed with ADHD. Both programs focused on creating a support system for students with ADHD, increasing self-esteem, and increasing interest in engineering education by students with ADHD. The study pointed out that individuals with ADHD are underrepresented in engineering due to their neurodiversity and the study sought to find a way to encourage interest in engineering by improving the students' self-esteem through the use of positive psychology with the hopes of making the engineering field more diverse. Both pilot studies were overall successful, but there were several areas where they would like to improve recruitment and program staff training. Because these were only pilot studies they do contain explicit results, but the authors indicated plans to continue their research.

The second article also focused on a humanistic approach through self-determination and motivation frameworks. The Gero [43] study trained 13 engineering students at the Israel Institute of Technology to teach mathematics, physics, chemistry, biology, and computer science at eight different high schools. The 13 engineering students participated in "Educational Clinics" in which they focused on teaching skills to use once they were in the high schools. By providing teaching guidance it better prepared the engineering students for teaching to improve the instruction. The engineering students completed three different questionnaires one at the beginning of the course and two different sets of questions at the end of the course asking the students to look at their motivational factors and fulfillment of student needs. The study found that the course met the students' expectations and that more intrinsic motivation and self-confidence was apparent at the end of the courses.

The final two studies in this section were very similar in their theory, framework, and design. Both studies took place in the state of Texas and focused on the underrepresentation of Hispanic college graduates in the STEM field. Both studies also used the expectancy-value theory framework to link intrinsic and utility values to encourage participation in STEM to help student awareness in physics careers, increase participation in physical science programs, and increase interest in studying in STEM programs. Both studies used pre- and post-surveys to provide feedback to the success of the science programs. One study focused on a physics career day involving high school students [44]. University faculty and senior students directly participated with the students in hands-on activities to create interaction and expose students to the STEM field. The study found that through the physics day students increased their awareness of physics careers and by having senior students of a similar demographic involved this helped to alleviate fears around physics in general. The second study led by the same first author [1] used a similar format and created a "Physical Science Day" geared at Hispanic high school students again. This study found that student interest in studying chemistry, physical science, and physics all increased due to the physical science day and provided exposure to new careers, great learning experiences, gained knowledge of science programs, motivated students to pursue college, and helped them better understand the critical demand of STEM graduates. Again, both programs utilized a humanistic theoretical approach to connect with the whole student and focus on personal growth and interest through knowledge gained.

## Gaps

One of the most notable findings was how many articles were removed from this review due to lack of inclusion of their guiding theoretical basis. It is important, as engineering and physics outreach is conducted, that the development is well-grounded in theoretical pedagogies. However, learning theories are not typically part of physics or engineering collegiate or graduate training. If replicability and transferability of outreach programs are desired, those conducting the outreach program, and the research that supports it, must begin with a theoretical foundation. Table 1 can be used as a starting point for clarification on which learning theory best supports a specific outreach program. In addition, some of the articles included in this review indicated clear framework or model guidelines that were used in the study, but some of the frameworks were not accepted learning theories by the educational psychology community. Therefore, theoretical foundations were supplied based on the frameworks or models used. It was the authors' decision for this literature review to group the articles by large, recognized foundational learning theories to help guide this review process.

It is also of note, that one prominent learning theory were not seen in any of the articles. Behaviorism is the "theorical perspective in which learning and behavior are described and explained in terms of stimulus-response relationships" [10]. It is the authors' speculation that behaviorism did not guide any of the outreach programs found because behaviorism relies on extrinsic motivation instead of intrinsic motivation to change behaviors. Out of the studies discussed in this literature review, intrinsic motivation was a compelling force used in many of the articles which would eliminate the use of behaviorism as a theoretical foundation.

There are also gaps in the assessments of the articles. Not every article that was selected included data about the success of the theory or framework used. This absence of data makes analysis difficult in any large-scale review. It is the authors recommendation that as STEM outreach research continues that in addition to beginning with a theoretical foundation that researchers also include a discussion about why a particular theory was selected and how that theory was assessed in their overall findings. By connecting outreach activities to supporting theory and aligned assessment, others are able to replicate practices by knowing how to conduct the outreach and why the outreach was conducted that way.

## Implications for Future Outreach

By considering the articles of each overarching learning theories collectively, several insights were gained for future outreach activities. From the articles related to cognitivism, two insights were found related to outreach development and implementation. First, when developing outreach activities, university participants should consider ways to reduce extraneous load on outreach participants to support the learning of new skills and content. This could mean breaking the content into sub-goals or using simple typefaces when presenting material. Second, as outreach programs have the potential to shape participants beliefs about who engineers and physicists are and what they do for the world, implementation of outreach programs should include representatives of participant populations, especially if URC or females are a target audience. From the constructivism articles, the importance of providing scaffolding and points of connection to knowledge outreach participants already possess can be seen. This could be facilitated by reviewing grade specific standards and children’s literature on relevant topics to see what vocabulary and concepts will already be familiar to outreach participants. The articles related to contextualism, experientialism, and humanism highlight the capacity of community-focused outreach for fostering a sense of belonging to the discipline and community of engineers and physicists, thus assessments of outreach activities guided by these learning theories should relate to the impact of sense of belonging. The contextualize articles also pointed out that the context of an outreach program should impact the activities. Social, industrial, and geographical context can be a source of inspiration for outreach content and activities. Table 3 lists common goals of university-driven K-12 outreach, along with aligned learning theories and frameworks. The choices related to alignment were driven by the reviewed articles, i.e. one or more of the articles reviewed had that goal and used those theories and frameworks. However, in an effort to streamline the search for someone desiring to implement a new outreach program with a similar goal, only two of the more prominent frameworks for each goal are included. This table can be used by engineers and physicist seeking to begin or modify outreach activities with these specific goals in mind.

Table 3: Overview of high-level outreach goal connections to learning theories and potential frameworks.

| If outreach goal is to: | Aligned Theories: | Aligned Frameworks |
|---|---|---|
| Address community need for more engineers and physicists. | Experientialism, Contextualism | Sociocultural Theory, Logic Model |
| Provide engineering student participants with agency and sense of belonging. | Humanism, Experientialism, Contextualism | Service Learning, Sociocultural Theory |
| Provide science and engineering role models for URC and women. | Contextualism, Humanism | Motivation Theory, Positive Psychology Theory |
| Show that physics and engineering are exciting! | Experientialism, Constructivism | Design-based Learning, Service Learning |
| Provide learners with authentic, complex problems to explore. | Experientialism, Constructivism | Project-Based Learning, Service Learning |
| Introduce specific content. | Cognitivism | Logic Model, Cognitive Load Theory |
| Introduce specific skills. | Cognitivism, Constructivism | Logic Model, Cognitive Load Theory |
| Show outreach participants that they are capable of becoming engineering and physicists. | Humanism, Contextualism | Sociocultural Theory, Situated Learning |
| Increase the pipeline of potential engineering and physics students. | Contextualism, Cognitivism | Situated Learning, Logic Model |

## Conclusions

Through performing a systematic literature review on university-driven K-12 outreach, five learning theories were identified as guiding outreach development, implementation, and assessment. However, much remains to be explored related to the role of each of these learning theories in engineering education. Of the original 216 articles identified, only 37 included a clear theoretical pedagogical grounding. These articles used the five key learning theories of cognitivism, constructivism, contextualism, experientialism, and humanism. Each of these learning theories can help outreach developers understand how to best support outreach participant learning. Through pairing and communicating supporting learning theories, organizational structures, and outreach goals outreach developers can aid in future outreach implementation by others.

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