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STEM Outreach: A Literature Review and Definition

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***Abstract* – Science, Technology, Engineering and Math (STEM) professionals are in demand to meet the current challenges within our society. STEM outreach plays a critical role in promoting, understanding and increasing interest in the STEM disciplines. Outreach activities provide a unique platform to reach students through many delivery methods and audience tailoring that bring impacts otherwise unattainable through standard curricula. This work presents a literature framework and review of works that pertain to the STEM outreach system. From this review, a practical definition of STEM outreach is presented. The overall purpose of this work is to expand and aid in the further research to optimize the benefits of outreach activities in the STEM fields to help prepare students for future STEM careers.**

Index Terms – Education; Engineering; Math; Outreach; Science; Stakeholder, STEM; STEAM; STEM-H; Systems, Technology

INTRODUCTION

Science, Technology, Engineering and Math (STEM) education continues to be a focus area within the education system, the political arena and the research community. Within the STEM domain spaces, many focus areas can be identified that promote STEM understanding, such as teaching methods, assessment tools, curriculum developments and outreach programs This work focus on the outreach area of STEM understanding, which continues to be one of the major methods being utilized to promote the STEM disciplines. The term '*STEM Outreach*' is used widely by many different stakeholders within the STEM community and can take on different meanings depending on parties involved or on how outreach content is provided. This work aims to provide a robust literature review of STEM outreach research that inclusively captures the role of STEM outreach activities across applicable domains.

To establish a baseline for the literature being reviewed, a graphical abstract is presented. The abstract was created using a deep learning tool. [1] This tool utilizes the full text of artifacts such as conference papers, journal articles, books, and other publications to look for similarities and cohesion of the information published. The result of ~82,000 STEM outreach related artifacts indexed from 29 individual databases such as IEEE, Wiley, MIT and SMPTE as illustrated in Figure I.

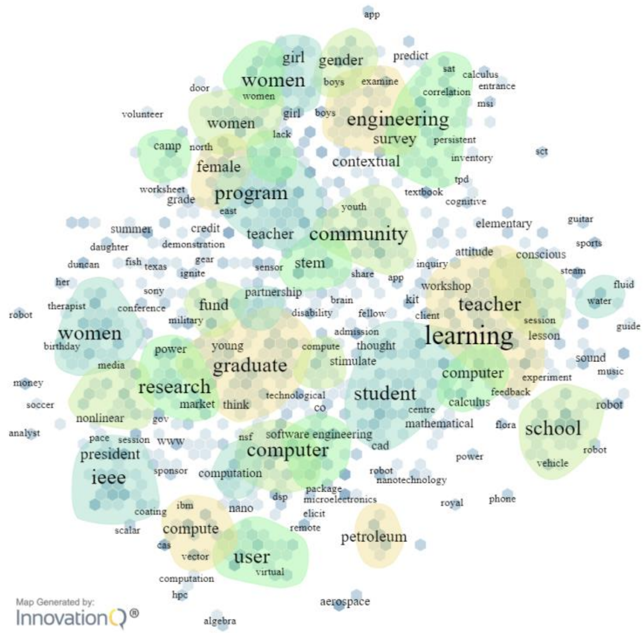

Figure I, STEM Outreach Graphical Abstract

The figure visualizes the top 1,500 artifacts identified by relevance to the search; Science, Technology, Engineering and Math Outreach. It should be noted that the full words for STEM were used due to the close affiliation of STEM to stem cell research making it difficult to separate the two areas of literature. A more detailed version of Figure I is found in Appendix II.

To accomplish the more detailed literature review provided in this work, a classification methodology has been developed and is presented as a tool to be used by researchers to continue to organize and track the growing body of research focused on STEM outreach. In parallel to this literature review, we developed a stakeholder analysis which is available under the title "STEM Outreach: A Stakeholder Analysis". [2] Further, based on the literature review and classification methodology along with the stakeholder analysis, a working definition of 'S*TEM Outreach*' is provided to give the STEM community a common definition to build further research in the outreach arena.

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PART I: METHODOLOGY

Publications related to STEM outreach were collected and reviewed from a variety of sources including IEEE, ASEE, Journal of Education, International Journal of STEM Education, Journal of Research in STEM Education, Journal of Engineering Education and many other sources. This literature review is not being presented as an exhaustive collection, as it is not feasible to fully collect every publication within the space. Due to this plethora of literature, a rigorous methodology was required to review and organize the literature. To start, the authors created a set of high level sub categories: *Students, Stakeholders, STEM content and Methods*. To organize the literature, each paper was reviewed and key aspects were identified and recorded in a collaborative spreadsheet document. This resulted in the construction of a classification system that allowed works to be binned into specific sub-areas, with further sub-division as necessary. It should be noted that within each category and subcategory an 'Other' category was utilized to provide flexibility to capture niche papers deemed worth including. Given the volume of literature under review, categorization has been simplified, such as 'target grade' using typical US grade bands to simplify data collection.

Collected literature was reviewed to determine if it falls within STEM Outreach. This created a difficult task for the authors to remain focused primarily on outreach while providing a robust literature review with adequate context. For example, a paper that focused on optimizing project-based learning (PBL) teaching methods within the classroom would not have been identified as a 'STEM outreach' publication but has been referenced as part of the Outreach Delivery Methods section. For the literature review, some of these outliers have been added if the authors felt it further strengthened the review of STEM outreach literature. Another example is if a teacher developed a method to illustrate a STEM concept that could easily be adapted for outreach it was indexed. Overall, documenting and analyzing sources that did not explicitly contain STEM Outreach content provided beneficial context, improved understanding of stakeholder needs, and captured methodologies that can enhance content delivered through STEM outreach activities. Appendix I illustrates the literature classification structure developed and is presented as a guide and expandable structure for others.

PART II: LITERATURE REVIEW

The literature review presented in this section classifies works by STEM outreach target ages, outreach methods, educational content, and assessment methods as outlined in Appendix I. The clear and consistent trends will be discussed in brief as they related to each of these hierarchical classifications. It should be noted that each subsection within the main sections easily warrants a full rigorous literature review by themselves; however, our goal was to provide high-level trends and insights within each section to build a systematic review of contextual information that will support the overall proposed definition of STEM Outreach presented at the end of the paper.

I. STEM Outreach Target Ages

STEM outreach can be found at all grade levels and ages. This section provides examples in literature focusing on specific age-based cohorts and global effects of STEM Outreach activities.

<u>Pre K - K Grades</u>

Initiating programs at the early stages has the obvious advantage of building STEM into the students vocabulary. Selecting age-appropriate activities based on cognitive ability and developmental stages leads the student towards exploration and play-based activities for this age group. [3][4] Outreach of complex STEM concepts can be presented to these early ages. In his work Danish developed programs to introduce Systems Thinking to students and illustrated that complex concepts can be understood by kindergarteners. [5] Danish does mentions that students experience difficulty relating to systems they lack direct experience with and need opportunities to build relevant vocabulary. In her works, Cunningham has illustrated the need to bring Engineering to Pre-K and kindergarten students. [6][7] Camp programs for kindergartners can be found that utilize engineering challenges. [8] Bottomly and Parry outline the use of playground equipment as an interactive tool to teach STEM to kindergartners. [9] Many successful initiatives also focus on integrating STEM concepts into playground equipment and age-appropriate games. [10] Outreach focused on bringing specific learning mindsets that frame play activities in ways that support learning STEM concepts for students can be found targeting audiences as early as kindergarten. [11] Torres & Casey's work on introducing electrical engineering to this same target group is well documented. [8][12]

<u>1st - 4th Grades</u>

Programs that focus on elementary school students are often focused on leveraging outreach delivery models to improve fundamental skill sets in arithmetic, reading, and basic analytical skills. A robotics based program developed by Cejka and her team focused on increasing math and science understanding. [13][14] While specialized education materials or programs are less prominent, they can be found such as Leon and Wilsons work to bring photonic engineering into elementary classrooms. [15] STEM based outreach that targets underrepresented students in this grade range can also be found. [16][17] To reach low resource schools, elementary aged students and families 'mobile laboratories' that bring STEM has been developed. [18][19] Programs using field trips are documented to aid students in making the link of STEM concepts to their surroundings and everyday lives. [20] Understanding the impact of outreach and the long term educational trajectory for elementary school students is difficult to measure. [21]

5th - 8th Grades

Middle school programs, similar to elementary school programs, can be found that focus on overall STEM understanding along with more specific STEM areas. [22] Vernaza, and Aggarwal, discuss outreach activities for middle school students delivered by undergraduate mechanical engineering students. [23] Other examples include outreach developed by Somerton and Ballinger on manufacturing engineering. [24] Due to this being considered a critical age range for career development, works to understand if outreach has a long-term impact can be found. [25][26] Todeschini and Demetry document a longitudinal study tracking 7th grade girls' interest in science and engineering based on outreach programs. [26] Many other programs focused on girls and other diversity groups in middle school can be found. [27]–[33] Although not expanded on deeply in this work, the area of diversity, inclusion and culture as related to education and outreach is well documented. [34][35] Summer camps focused on middle school students are also documented. [36][37] Another area to reference in the middle school range is the increase in team or project-based outreach. In these grades, the effects of peer groups' interest begins to play a larger role in student interests. Collaborative STEM projects can address this area through outreach activities. Stereotype susceptibility in children has been explored by Ambady's work. [38] Along with the Shapiro & Williams research in understanding the role of stereotypes related to STEM interests, both of these works point to stereotypes being established in youth in the 4th to 5th grade ranges. [39] Due to this factor team- or project-based outreach that focus on STEM can increase the likelihood that peers will positively impact each other while developing their own stereotypes. [40] Stein and Nickerson's work compared the effectiveness of STEM based outreach for boys vs. girls teams during a robotics based program as part of a middle school program. [41] They found that girls referenced the friendships in their team as one reason for being interested.

9th - 12th Grades

The high school grades are the final transition to formally selecting a career path. [42] To strengthen this, programs commonly focus on careers, such as career fairs and summer camps. Cantrell and Ewing-Taylor document an outreach program that brings college students into the classroom to present their research. [43] As with the other grade ranges outreach programs that bring specific STEM related topics into the classroom can be found. A materials based program called "Polymer Day" was developed by Ting and his team to introduce plastics to high school students. [44] Summer enrichment programs are also well documented, as these give students an opportunity to be fully focused on STEM concepts. [45]–[49] Emphasis on achieving high school graduation in underrepresented demographics coexists with efforts to achieve advanced career field placement and create research opportunities coordinated with post-secondary education institutions and professional groups. Many high school outreach efforts have a documented focus on girls and minority groups. [50]–[52] Salto and team found that these types of programs have resulted in more students from underrepresented backgrounds pursuing STEM degrees in college. [53] Stapleton and his team document a high school based outreach program that developed a series of high school classes that would result in college credits. [54] This approach allows for a local college to reach out to schools and help shape classes that can build skills and understanding, as well as a direct link to an undergraduate degree.

College (Undergraduate through Doctoral)

The second pivotal transition period for individual involvement in STEM outreach is during the college phase. In this period college students can simultaneously be both the target audience for STEM outreach programs, and also contribute substantially to STEM outreach efforts for younger age groups. [55] Houck and his team developed a one day science camp that his graduate students provided to elementary aged students. [56] This fosters the ethos of 'giving back' through educational outreach and has the obvious benefit of increasing the number of outreach providers and available programs support. [57] However, it also benefits the college student with enhanced networking opportunities, improved understanding of the pedagogy process as a whole, and enhances the students' self-perception as individuals who provide meaningful benefit to a field. [58][59] These networking opportunities were found across broad communities, including industry and government research opportunities. [60] Within the literature surveyed, many sources cited concurrent opportunities to enable student participation in advanced research. [61] Thus, research opportunities enabled college students to both accelerate academic pursuits and progress towards academic and career goals. [62] Underrepresented minority high school and college students report STEM-pipeline sustaining gains after participating in the Loma Linda University Summer Health Disparities Research Program.[53]

Other Target Ages

Indirect outreach that targets parents and other groups that frequently interact with children presents additional opportunities to create venues for sparking interest in STEM fields, and reach audiences beyond typical academic interactions. Multiple library based outreach programs have been developed that focus on reaching younger students but also have the benefit of reaching parents, extended family or other individuals in the community. [63][64] Baek's work highlights the ability to use libraries to bring STEM back into the home through community interactions. [65] However, the analysis of literature indicated that further research into STEM Outreach focused on other target ages is needed. One program was identified that utilized graduate students to provide outreach to lay adult audiences in an effort to increase STEM awareness. [66]

II. STEM Outreach Delivery Methods

STEM Outreach delivery can take the form of various methodologies, can carry diverse scales of efforts and levels of focus, and can be uniquely tailored to the population targeted. This section reviews literature that investigates or presents alternate methods to deliver STEM outreach content. These methods range from carefully developed programs with academic rigor to ad-hoc outreach leveraging current events, demonstrations, interactions in video games, or accidental discovery of natural phenomena. Using outreach content specifically developed to supplement and integrate with existing curricula and traditional pedagogy were also evaluated.

Lecture

Use of lectures as the means of delivering educational content remains the standard approach, and allows for re-use of content tailored for specific audiences. The primary pedagogy method used in K-12 and post-secondary education is commonly applied in STEM outreach cases, although often supplemented with other means of content delivery. Lecture as a pedagogy method can be enhanced through interactive techniques to increase student engagement. [67] Delivery of STEM outreach content via lecture can also be supplemented with technology, similarly to Wallace integrating iPads for earth science outreach education in the classroom. [68] Examples of lecture methods in outreach are numerous as they are typically used. [69]–[71]

Active Learning/Inquiry Based Learning (IBL)

Within literature surveyed, active learning as a pedagogy method shifts the role of the educator into more of an inquiry facilitator than source of information. This can take the form of teachers applying active learning for curriculum modules or outreach providers leveraging active learning techniques to increase student interaction. [35][72] Freeman and his team found that active learning methods improved performance in STEM related fields. [73] Use of active learning for K-12 audiences allows for responsive pedagogy that matches content delivery to student cognitive abilities and knowledge base. The limitations with active learning remain with the increased time required to address a chosen topic which can be less conducive for outreach activity constraints, and that educator preparation requires a fundamentally different approach. Robotics is a common example of active learning in outreach, which also links well with problem based learning methods. [74][75]

Problem Based Learning (PBL)

Across literature surveyed, a significant focus on using problem-based learning, and project-based learning frameworks to present STEM topics is found. These efforts aim to enhance student engagement with outreach content and allow for self-directed learning to expand student knowledge in STEM domains. Use of engineering challenges such as egg drops or spaghetti towers are common and have the advantage to be easily scaled depending on the student's age and time available. [8] For most outreach providers, the ability to focus on specific tasking with deliverables and timelines enables interactions that direct students towards advanced self-directed learning through research, analysis, and experimentation. [72] Work has been completed that demonstrates the positive link between problem solving and interest in STEM fields. [76] As previously mentioned robotics fits well within the problem-based learning framework. [77]–[79] Other examples of STEM based PBL can be found that focus on a specific STEM topic such as microfluidics. [80] Direct links to problem solving and computational thinking have also been documented. [81]

Workshops and Training Events

Workshops and training tend to focus on providing specific educational content to STEM stakeholders. This may include but is not limited to students, teachers, administrators, and outreach providers. These types of programs can be seen for specific knowledge such as geoscience or overall STEM. [82][83] Workshop and training opportunities for teachers are typically presented as opportunities for "teach the teachers" extension of professional development. [84][85] Extending training opportunities to each of these stakeholders provides indirect benefit to students. This clearly helps improve the education process through providing opportunities to introduce improved pedagogy methods, updated curricula, and introduce subjects outside of typical curriculum. Allowing for K-12 educators to participate in summer workshops or research internship opportunities within STEM fields facilitates the teacher's development towards gaining unique perspectives and understandings of STEM disciplines. This further creates opportunities for teachers to become embedded career field role models in addition to existing educator roles. [86][87] These types of programs have also been found to be effective in introducing and bringing new emerging technologies into the classroom, such as 3D printing. [88]

Camps & Events

Focused STEM programs outside of the typical school structure often take the form of camps and planned events. Summer camps, weekend events, and academic competitions such as science Olympiad or science fairs create focused active student participation. [46], [89] Many of these programs, such as the science Olympiad mentioned prior are located throughout the world. [90], [91] Binns and his team document an increase in some STEM interest and future career pursuits from camps they conducted. [92] Kong and team also support this finding, documenting increase in STEM career interest of students who went to a STEM camp over those who did not. [93] As would be expected, a large range of camps focus on specific areas, such as robotics, geology, astronomy, or computing. [94]–[97]

Other Delivery Methods and Considerations

Other methods of delivery have been documented, such as Lyons and Pasek's work developing a museum exhibit utilizing gaming to promote STEM interest. [98] Another unique method of delivery developed by Jones and her team is the use of a mobile STEM laboratory, bringing hands on activities to Seattle area low resource schools. [18] STEM based clubs are another delivery method identified in the literature. These can be conducted during or outside normal school hours. [99][100] Also multiple delivery methods may be used during any one STEM outreach program. [77] Some work has been done to quantify the effectiveness of different delivery methods or environments. [101][102] Although not documented in the literature well, ad-hoc STEM outreach does occur. [103] An example could be a mother pointing out the rainbow light patterns of oil floating in a parking lot puddle and describing light diffraction. While the majority of research cited is focused on deliberate and planned STEM outreach activities that leverage the pedagogical structures and methodologies of traditional delivery methods, ad-hoc and spontaneous exposure to STEM concepts has been previously demonstrated to be a significant factor in students continuing to pursue career goals involving STEM pursuits. [77]

III. STEM Outreach Content

Within the STEM Outreach literature reviewed, a large body of work is focused on the STEM disciplines and the synergy between. The following sections will provide examples of STEM outreach efforts within these categories. Further examples will be provided that dive deeper into specific sub categories as needed.

Science

STEM outreach programs focused specifically on the aspects of science are numerous, and vary greatly in scope. Programs targeting specific aspects of science have been developed as outlined in the following sub categories.

Earth Science: Current K-12 curriculum contains basic coverage of earth sciences, but offers students finite exposure to the core fields of geology, meteorology, climatology, and oceanography. [82][104] STEM outreach can expand on the understanding students have of earth science principles and the importance of these fields in their daily lives. Examples include utilizing soil mechanics to teach basic earth science principles. [105] Utilizing graduate students to provide outreach in their research area such as ocean dynamics. [106] Wallace and Witus documented positive findings based on using iPAD ® based technologies for earth science K-12 outreach. [68]

Physics: Introducing concepts from the fields of physics early in academic development carries substantial benefit, as a basic understanding of mechanics, optics, electromagnetism, and fundamental forces can benefit future learning and reinforce the importance of science for a K-12 audience.[107] Specific examples within literature focusing on physics through STEM outreach include utilizing ropes courses to allow students to experience the laws of motion, or using Lego robots for introducing physics fundamentals and specific principles such as fluid flow rate.[108]–[110]

Material Sciences: Exposing students to the critical role materials play in everyday life and how transformative those changes can be over the future can generate interest in the science and engineering required to develop and harness novel materials. Examples of outreach that try to increase understanding of material characterization and development of novel materials. Outreach camps focusing on material science by introducing participants to material properties and manufacturing processes can be found. [111] Outreach programs have been developed to build awareness of more obscure material science topics, such as a Navy based program focused on metrology. [112]

Chemistry: The core curriculum in K-12 chemistry education covers the fundamentals areas of the Dalton model, states of matter, chemical bonds, and stoichiometry. Although this provides a base, students have limited exposure to the major subfields of chemistry and the real-world applications of these areas in daily life. Chemistry based outreach can fill this void. [28][56] STEM outreach can provide a means of interactive demonstrations and activities allowing students to directly relate to chemistry content, and exposing them to career subfields within the discipline. [44][113] Working to make Chemistry more accessible, Kerby and her team developed a theater based outreach program to teach chemistry. [114] Levine and DiScenza created a clever 'sugar' based chemistry program to relate and reach students. [115]

***Biology*:** Extending existing biology curriculum and expanding upon existing models in the standard curriculum carries advantages for students, with outreach providing K-12 students to interdisciplinary fields such as neuroscience and bioinformatics. [116] Introducing students to the techniques and tools used in biology research can have benefits. Gomez and her team introduced BLAST and DNA PCR processes and demonstrated significant improvement in student interest and understanding in biology fields over a three-week summer internship. [117]

Other Science Based Literature: Among the subject matters that emerged outside of traditional scientific disciplines was introducing Systems Science concepts and methodologies to high school and undergraduate students. The promising opportunities present with introducing these concepts warrants further study in the eyes of the researchers.

Technology

Outreach efforts focusing on technology and its applications include introducing students to robotics, small unmanned aerial systems, additive manufacturing, electronics, and computer technologies. These efforts are frequently updated to incorporate new trends and real-world technologies.

Robotics: A large amount of literature is focused on using robotics for STEM outreach; leveraging the innate interest in robots made accessible through outreach activities generates substantial interest in K-12 age groups. Specific enabling tools for robotics can support age-appropriate cognitive expectations, such as the use of Lego® based systems. Talley and his teams work to measure conceptual understanding using these types of robots, or using small unmanned aerial systems kits for older age groups. [61][118]

Manufacturing & 3D Printing: Manufacturing remains a discipline not directly available to most K-12 students despite demand from various career fields for skills in manufacturing and related areas. Kim and Cossette document an outreach program promoting collaboration between middle school, high school and colleges through field trips to local manufacturing companies. [119][120] Outreach efforts to promote the use of 3D printers in the classroom and support teachers can be found. [88] While rapid prototyping and computer-aided design are transformative technologies to the current workforce, introducing these areas to today's K-12 students will be the baseline from which future advancements will be made. [61]

Electronics: Designing age-appropriate activities using electronics continues to be a cost-effective way of engaging students through outreach activities with students developing an understanding of real-world applications. As an example, Bottomly successfully used both Hexbugnano and Adafruit LED kits in outreach programs to make activities collaborative and appealing to girls. He also showed how this student experience can be tied directly to search & rescue remotely operated systems, or medical monitoring devices. [121] Many of these outreach programs also build STEM technical skills such as soldering.

Computer: Expanding the appeal of computer science can also be achieved through leveraging existing video games with constructive themes, with examples such as using Minecraft with tutorials to support self-directed learning. [122][123] Nche succeeded in creating virtual learning environments that garnered active involvement from underrepresented student groups, and supported active professional development for teachers in black communities. [124] Acharya documented use of programming competitions to directly benefit high school students learning computer science and coding skills. [125]

Engineering

Introducing K-12 students to the concepts and real-world fields of engineering is predominately an outreach-centric activity across the literature surveyed, with significant benefits observed in creating interest among specific student age groups. [126]. Engineering outreach activities also introduced students to a variety of interdisciplinary fields of study at earlier ages. Programs can be found that cover multiple engineering areas at the same time such as the UK based space outreach program, Blue Marble. [127] The following sections discuss specific engineering fields.

Electrical: Electrical engineering programs vary in complexity and target audience, and can also be found focused as early as kindergarten level. [12] For older students the reliance on physics and basic circuit knowledge determined how outreach providers were able to tailor modular outreach content around converging on the unified concepts of electromagnetism, and experience positive results with more hands-on activities. [128] Hands-on based outreach for high school students can be found that focus on electricity and magnetics. [129]

Computer: Introducing computer engineering and basic concepts of cyber-physical systems for K-12 audiences spans a remarkably wide spectrum of introducing students to coding at early ages and introducing core concepts such as variables, operators, conditional statements, and loops. [124][130]

Mechanical: Introducing mechanical engineering and design concepts is an area well documented within the STEM outreach literature. Impacts to K-12 student groups, including showing what professional engineers do can reflect positively on interest in engineering fields. [21] Other efforts involve using the appeal of Rube Goldberg and similar contraption-based projects to make mechanical engineering concepts accessible and appealing to 5th and 6th grade students, or using hands-on project-based learning modules delivered through outreach kits for marine engineering. [131][132] Naturally mechanical engineering is embedded in other programs that focus on design. [20][133] Examples of undergraduate Mechanical Engineering students providing outreach have been documented, these programs can promote mechanical engineering along with other STEM disciplines. [134]

Chemical: Activities allowing students to explore hands-on chemical engineering activities include simpler demonstrations appealing to younger grade levels, and more direct experimentation in pharmaceutical chemical engineering processes by quantifying dissolution of ibuprofen using UV-Vis spectroscopy that left students with a better appreciation for what chemical engineers do, and why it matters in everyday life. [111][135]

Bioengineering: Developing hands-on student activities for K-12 students with applications to bioengineering, coupled with tours of working facilities allowed students a window into bioengineering as a discipline. [136] The applications to everyday life are quite apparent to students, although tailoring physiologic and tissue engineering concepts for K-12 audiences is more challenging than examples related to drug delivery and prosthetic devices. [135]

Other: Engineering concepts that are not tied specifically to individual disciplines, and particularly those which fall under the Systems Sciences emerged as a specific opportunity where STEM Outreach activities can provide meaningful content delivery that would not otherwise be available to K-12 students, or even undergraduate students. For implementation purposes, positive examples come primarily from medicine and similar healthcare fields, which tend to lack direct K-12 pathways. [137] Medical based engineering has been found to an effective way to promote STEM to girls. Importantly these unique engineering disciplines require the same basis in STEM fundamentals to prepare students for specific domain education and subsequent careers in those areas. Future research directions of incorporating Systems Sciences concepts, methodologies, and generating K-12 tailored curriculum delivered through STEM Outreach venues should be pursued. The value of this effort is suggested by the literature surveyed to be tremendously valuable for both systems engineering as a field, and for students interested in pursuing careers within systems engineering. [138] Students can benefit significantly in any career field with improved understanding of complex systems, trade spaces, and creating mental models based on abstraction and relationships. [139]–[141]

<u>Math</u>

One of the most significant predictors of academic performance for K-12 students achievement is mathematics. [142] STEM outreach efforts that support K-12 development of math skills demonstrated benefits for students across STEM and related domains, as achievement and problem-solving abilities remain highly correlated with scholastic achievement through post-secondary education, and even career outcomes. [143][144]

Fundamentals: Math fundamentals and understanding represent the base building blocks throughout STEM. The critical importance established in education literature for K-12 students to understand arithmetic and algebraic concepts and be able to accurately calculate results directly correlates to retaining student interest in fields where mathematical calculations are requisite. [145] The fundamental problem-solving skills developed by solving math problems necessarily involve the process of developing structured viewpoints to address problems and subsequently work stepwise through each aspect of the problem. [146][147]

Mathematical Reasoning and Algorithms: Using mathematical computational methods can not only further understanding of the nature of numbers to support intuitive understanding of mathematical operators, but also be leveraged to support problem-solving skills applicable to other domains. [148] Miller and Wang conducted large scale surveys and determined that middle school students can improve academic achievement by focusing on mathematics indicators. [149]

Computer: Incorporating mathematical concepts applicable to computers, and converting understanding of the nature of numbers into the operation of computer systems is indirectly contained in current K-12 curriculum, but is still enhanced through outreach content. Frye demonstrated mathematical concepts presented in MATLAB can be applied to real-world problems such as environmental sustainability, and biologically-inspired robotics. [145][150]

Other Mathematics: Outreach activities also provide opportunities to present additional mathematic concepts, to include statistics, data analysis tools, and applied math. [151] Introducing concepts such as topology and spatial connections to 3-D shapes to gifted middle school students, DeJeagher successfully demonstrated that these concepts can be integrated into a scaffolded knowledge framework that is useful for K-12 students. [152] The delivery methods vary depending on the audience, quite frequently the demographic make-up of the student body a mathematics outreach effort is targeting will dictate the best option. [153] Importantly Weis observed that many science, engineering, and other technical domains are inherently scaffolded upon the K-12 mathematics knowledge base, and without general proficiency in mathematics a focus on preparing students for college in these areas becomes untenable. [154]

<u>Other STEM Related Areas</u>

Science, technology, engineering and math are naturally the four main focus areas of STEM, however incorporating literature, arts, and healthcare content into outreach efforts can improve student engagement and benefit from these activities. A key advantage for STEM Outreach is the ability to leverage interdisciplinary goals of a specific outreach program, leading students to combine knowledge, concepts, and methodologies from disparate fields in order to achieve specific goals, which is often difficult to achieve within traditional pedagogy.

This observation in other educational domains has led to unification of education into 'Humanities' blocks, generating a fusion of subject matter from literature, history, art, music, social sciences, and writing into combined curricula with great effect. [155] Literature surveyed shows other areas worthy of further discussion, including cross-pollination of ideas across disciplines, and a dependence on concepts already well taught in humanities blocks of subjects. For cross-pollination, a key advantage of STEM Outreach is the ability to break students' daily routine encouraging and leading them to combine knowledge, concepts, and methodologies from disparate fields in order to achieve specific goals, which is often difficult to achieve within traditional pedagogy.

The term STEAM has been established to further strengthen and foster awareness of the strong link between the arts and STEM. Some methods utilize art focused areas but enhance the STEM aspects such as a guitar building program documented by Hauze and French. [156] Henriksen and Danah argue in their works on the benefits and how creativity is enhanced when the arts are incorporated throughout the STEM fields. [157][158] The relationships between STEM domains and the arts relates to underlying similarities in cognition, with arts reaching individuals at a more visceral level. [159][160] Incorporating artistic design into outreach projects is a technique used to maximize engagement of female students, as well as emphasize aesthetic considerations in real-world applications for medical devices. [135]

Other fields with related interest to STEM domains include STEM-H (to include healthcare as both a scientific and practical discipline) or STREAM (adding both the arts and religion constructs). [161] Outreach focusing on healthcare fields follows the same patterns of intervention, with attempts from various medical fields to utilize active learning, general introductions to specific fields, and assessing attitudes of the field in general. [162]–[164] The majority of efforts to generate integrated curricula and allow students to more fully explore problems that exist across these multi-domain spaces mirror the outreach delivery of STEM content.

IV. STEM Outreach Assessment Methods & Tools

Outreach efficacy measurement typically leverages survey methods, including interviews with students or other stakeholders. Surveys with accompanying data analysis can effectively quantify STEM interest and capture information about the efficacy of programs. Interviews with outreach participants or providers allows for selective focus on what outreach activities are effective, and can identify specific events, interactions or opinions that can measure program effectiveness or document opinions.

Methods and tools to measure interest and appreciation within the STEM disciplines have been in use for decades. As an example, Fraser published a tool in 1978 to measure if students enjoy science. [165] To expand beyond just interest, researchers began to develop tools that measured the relevance of science and society, such as Siegel and Ranney's work. [166]. This tool designed for high school students indicated a high-reliability factor of 0.91. Tools for lower grades have also been developed, Lamb and his team developed a tool starting in 5th grade through high school. [167] The Measure of Affect in Science and Technology (MAST) tool is one of the most recent tools developed utilizing both classical and Rasch measurement perspectives focused on middle school students, indicating a 0.95 reliability factor. [168] This looks to be an enhanced version of a prior tool by the same group that was developed for college-level students.[169]Peterman and her team developed tools to measure STEM interest utilizing a questionnaire heavily focused on student career interests. [170] This was achieved by focusing on three distinct factors, interest, intent, and importance. Similarly, Hillman and her team also developed an attitude tool that measured interest for science and career path but also added the value of science to society and the perception of scientists, thus expanding the measure of importance and adding role model perceptions. [171]

Most of these tools were not specifically developed to cover all of K-12. The tool developed by Tyler-Wood, Knezek, and Christensen applies to Elementary grades and higher. [172] This tool uses surveys to measure interest in 5 key areas: Science, Math, Engineering, Technology and Career Path, through a series of questions. Tyler-Wood asserts a reliability factor from 0.84 to 0.93; this range is due to different reliability factors for each of the 5 categories. It should be noted even through Tyler-Wood asserts that the tool is effective for 1st -12th grades, the reliability factor values were only validated through middle school pilots. Another promising tool recently funded for development by the National Science Foundation (NSF) is the Dimension of Success (DOS) observation tool developed by PEAR Institute to take objective measurements across a broad range of STEM program categories. [173][174] The DOS which is part of the Common Instrument Suite (CIS) was developed specifically for outreach programs to measure an overall picture of STEM outreach impact. The CIS is constructed around two main themes: STEM-Related Attitudes and Socio-Emotional Learning. This tool is designed to be tailorable depending on the window of opportunity to survey students, designed for both longitudinal and pre/post event surveys. Further, CIS data collection will allow for deeper data analysis, including student demographics such as gender, race and geolocation.

Through K-12 there are rubrics developed across STEM fields, which are widely accepted methods of measurement and if administered properly have been found to increase effectiveness in the classroom. Traditional rubrics have been developed for the classroom setting and for outreach programs. [175] Andrade's work in developing what she calls an 'Instructional Rubric' aids teachers and students with learning, evaluating and accountability of materials.[176] Montgomery confirms this assertion in her work and references that rubrics also allow for 'feedback for improvement'. [177]

V. Other Related STEM Outreach Literature

The following subsections further outline other groupings of literature that were identified and considered important to document.

Career Path

Developing the STEM career pipeline is a theme found within the literature. [178][179] Blickenstaff and others have highlighted many of the ways female students drop out of the STEM pipeline. [180]–[182] Lesser known field such as geoscience have developed frameworks in hopes of increasing interest in their specific fields. [183] Camps provide an immersive environment that have shown to aid in students identifying new career paths. McGranna and his team found that 65% of those who participated in the 10 day camp on Sustainability Engineering identified new career possibilities. [184] As discussed prior, specific programs or tools have been utilized under the theme to support the STEM pipeline. [185][186] The overall systems career development framework has been well documented and articulated by Patton and McMahon. [187] In their numerous works they outline the multiple theories and constructs that impact career development. Interestingly, the influence of ad-hoc or accidental events as previously described can be seen in their framework under the category of 'chance'. Dorsen, Carlson and Goodyear identify 6 contributing factors that lead to STEM career choice outside of the formal classroom. [188] Due to the ability of STEM outreach to significantly impact these factors they have been listed out below for reference:

1) *STEM Career Awareness & Discussion*
2) *Academic Preparation and Achievement*
3) *Identification with STEM Careers*
4) *Self-Efficacy (believe in themselves, confidence they can do STEM)*
5) *External Environmental Factors (barriers & support)*
6) *Interest, Enjoyment and Motivation*

One other area that should be mentioned is the students' mindset impacting the career development pipeline. [189][190] Dweck's work is well accepted on the importance of having a growth mindset, which is needed to excel in the STEM fields. [191] This is expanded by Godrey and his team with their ELLI tool that measures seven factors that indicate a life long learning mindset. [192], [193] Other influencers such as aptitude tests can impact the career choices of students as they move through the pipeline towards a STEM career. [194]

Products

Across literature surveyed, a variety of products are used in STEM outreach activities in the form of classroom supplements, outreach kits and video games with educational applications.[61][94][122][123][132][135][195] Though many outreach-centric kits require additional training of teachers to fully support curriculum delivery through non-traditional means, student response to non-traditional delivery of content is often substantially different, and enables the delivery of unique outreach content to underserved and at-risk student populations. [124] Many of these products have developed rubrics and documents linking to science standards.

Strategy/Architecture

Examples of strategies and unique systems architecture methods related to optimizing STEM outreach can be found. [196] Using a systems engineering approach, Ward developed a STEM outreach methodology. [197] The US Army outlines a 10-20-30-40 rule to balance the types of interactions with students. [198] Eilam and his team outline a university based STEM outreach framework that provides a strategy to reach students that was implemented in both Australia and Israel. [199] Some of these used Systems tools such as Stephens and Richey's work with adaptive systems. [200] Other models have been developed focused around sub sections of outreach such as mentoring. One example of this is the document by Pluth and his team for a middle school and high school based program that utilizes University of Oregon students to conduct outreach and act as mentors. [201] The US Army highlights the positive impact on employees who conduct outreach and community awareness.[202] A method of using an E-Matching strategy is documented by Rumala and her team in an effort to utilize the existing community to impact STEM. [203]

Programs

There are vast amounts of STEM outreach programs throughout the world. For example, the R&D Council of New Jersey indexed 17 STEM outreach programs provided by minority serving institutions within New Jersey. [204] Examples such as the program developed at Robert Morris University document a larger STEM outreach program designed for both students and teachers. [143] Other even more robust programs include the US Army's Picatinny Outreach effort that reaches Pre-K through graduate students through outreach, teacher training, school administration consulting and conducting STEM education research. [198] Within the literature reviewed many examples of individual outreach programs can be found. The development of a world/nationwide network to aid in linking STEM outreach programs appears to be lacking within the literature. Some entail efforts can be found such as the STEM Ecosystem Initiative, but it is still considered to be a major challenge. [205]

PART IV: PROPOSED DEFINITION OF STEM OUTREACH

The purpose of this section is to use the reviewed literature, stakeholder analysis and ontological heuristics to construct a proposed definition of STEM outreach. [2] Before presenting the proposed STEM outreach definition, the construct of outreach needed to be considered in relation to its role within STEM education. STEM education has been previously separated within two constructs: formal and informal. Formal falling into the traditional school models. In their work, Dorsen, Carlson and Goodyear define informal as all experiences and activities that happen outside of the school setting. [188] Within the informal construct there are some references to accidental or ad-hoc STEM exposure, where the target stakeholder is introduced to STEM concepts indirectly or without direct planning as discussed previously. These three areas (Classroom, Outreach and Ad-Hoc) overlap and support one another. For example, outreach can be conducted within the classroom setting. Another more abstract construct with wide variance that is more abstract or can vary widely that should be considered is understanding that is developed through self-exploration. This can be influenced by STEM outreach but may not be a direct influence as there is no secondary party involved in the growth of STEM understanding, unless self-exploration as a mindset is being introduced. The opportunities for life-changing experiences where students are exposed to STEM activities through field trips, camps, workshops, mentorship and other activities all serve to build students confidence that they can succeed in STEM. [206] The ways in which these prominent outreach interactions are distributed across the STEM understanding model is illustrated in Figure III.

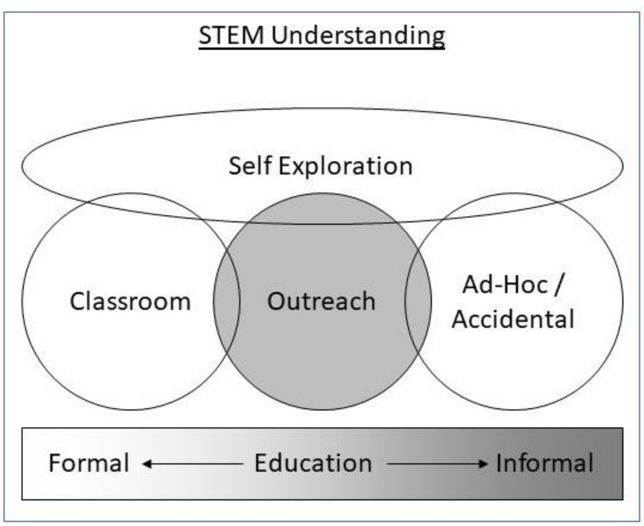

Figure III, STEM Understanding Model

Moving from left to right within Figure III illustrates the formality of education, while moving up and down represents the range from self to externally directed. It should be noted that accidental could also overlap with classroom. To construct the definition and ensure heuristic completeness, various ontological hypotheses were tested to ensure that the stated definition captures an adequate and appropriate scope for STEM outreach within a contextual framework of STEM activities and educational outreach. The illustrative example selected is leveraged from the Scaled Agile Framework, using the SAFe Agile hypothesis for each epic. The format for a value stream can be repurposed as a value added mechanism for the outreach framework architecture as defined. [207] Using the ontological format taken from the epic hypothesis statement table results in:

for: <customers>
who: <do something>
the: <solution>
is a: <something - the 'how'>
that: <provides this value>
unlike: <incumbent, competitor, non-solution alternatives>

Using this structure, the definition was constructed through the following statements:

for: <outreach stakeholders>
who: <are involved in STEM disciplines>
the: <STEM outreach activity>
is a: <means of delivering STEM content>
that: <increases understanding, awareness and interest>
differently than: <traditional student/teacher relationships>

Capturing similar ontological heuristics results in comparable determinations for completeness of this definition, further delineation is not required to capture the comprehensive scope of outreach activities across the greater STEM education framework. Based upon this methodology, literature classification, review, referenced stakeholder analysis, and the construct of outreach activities, the following proposed definition of Science, Technology, Engineering, and Math (STEM) Outreach is provided:

The act of delivering STEM content outside of the traditional student/teacher relationship to STEM stakeholders (students, parents, teachers…) in order to support and increase the understanding, awareness, and interest in STEM disciplines.

CONCLUSIONS

Based on the large amount of literature focused on STEM education and outreach activities that directly support STEM education for K-12 students, a highly inclusive definition of STEM outreach activities was developed, and can support ongoing research to continue enhancing student achievement across STEM domains through traditional and outreach methodologies. One of the most important findings across the entire breadth of STEM outreach content is that regardless of the specific domain and field from which outreach content was focused, much of the fundamental learning benefits are portable to other STEM fields, and across larger domains of metacognition and self-actualization for students. A more detailed stakeholder analysis has been performed, and published separately under the title "STEM Outreach: A Stakeholder Analysis", including identification and mapping of stakeholders and their interactions to further understand the STEM Outreach ecosystem. [2] Further work can also be conducted to build deeper literature reviews within each of the sections discussed. From these efforts, further optimization for STEM outreach programs can be achieved.

The authors would like to express their admiration and give thanks to the hundreds of authors who took the time to document and publish their research, along with the stakeholders who developed and provided the many STEM outreach programs reviewed. As a whole it is humbling and motivating to see the breadth and depth of efforts being conducted to ensure we have the next generation of Engineers and Scientists to solve the challenges we face today and in the future.

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APPENDIX I: Literature Classification Structure

STEM Content

- Science
  - Earth
  - Physics
  - Materials
  - Chemistry
  - Biology
  - Other
- Technology
  - Technology
  - Robotics
  - MFG & 3D Print
  - Electronics
  - Computer
  - Other
- Engineering
  - Electrical
  - Computer
  - Mechanical
  - Chem/Bio
  - Other
- Math
  - Fundamentals
  - Computer
  - Algorithms
  - Other
- Other Areas
  - Healthcare
  - Arts

Delivery Method

- Lecture
- Active Learning
- Problem Based Learning (PBL)
- Workshop/Training
- Camp/Event/Club
- Other

Assessment

- Survey
- Longitudinal
- SME Opinion
- Methods/Tools
- Testing
- Other

Target Stakeholder

- Student
  - Female
  - Male
  - Under Privileged / Minority
  - Other
- Target Grades
  - Pre K - K Grades
  - 1st - 4th Grades
  - 5th - 8th Grades
  - 9th - 12th Grades
  - College (Undergrad - Doctoral)
  - Other
- Teachers
- Parents/Guardians
- Administrator
- Outreach Provider
- Other (Mentor, Role Models)

Other areas

- Career Path/Development
- Products
- Strategy/Architecture
- Programs
- Other

APPENDIX II: STEM Outreach Graphical Abstract