Inclusive Teaching Practices in Engineering: A Systematic Review of Articles from 2018 to 2023

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Abstract

Inclusive pedagogies have been used in education in different areas and times; however, their adoption in engineering has been relatively new. Due to their effectiveness for all students and to the increasing student enrollment with diverse backgrounds in engineering, incorporating inclusive pedagogies in engineering is a requirement. In this study, a systematic literature review (SLR) is conducted to examine the inclusive pedagogy progress and find widely applicable practices that ensure student accessibility. This study sought to answer the overarching research question: What is the current state, trend, and direction for the future related to inclusive teaching practices in engineering? The SLR process included three phases: identification, screening, and synthesis. In the identification phase, seven search terms (inclusive pedagogy + engineering; inclusive teaching practices + engineering; inclusive classroom approaches + engineering; inclusive classroom methods + STEM/engineering; inclusive college classroom + engineering/STEM; inclusive instruction + STEM/engineering; and inclusive college education + STEM/engineering) were used to retrieve articles from different databases. The databases include Web of Science, Google Scholar, IEEE Xplore Library, Scopus, ERIC, Wiley Online Library, and Compendex.

Forty-four articles remained in the pool. Finally, in the synthesis phase, these articles were critically reviewed following the sub research questions, and the information was synthesized to generate themes. Five themes emerged from the forty-four articles. First theme: Using Identity to Foster Engineering Connections, found to be especially helpful for marginalized students. Second theme: Using Technology to Spread Inclusivity, which was particularly helpful for students who had disabilities, those unfamiliar with the language courses were taught in, or the ones who suffered from anxiety. Third theme: Including Student Interests in Engineering, helpful for all students and students who were unfamiliar engineering material. Fourth theme: Active Learning Skill Development for Marginalized Students, where underrepresented students had a way to engage more comfortably and learn career skills. Fifth theme: Inclusivity Pitfalls and Future, which revealed existing problems in engineering pedagogy framework and described places where it failed underrepresented students. These findings are relevant and timely as engineering education is growing and witnessing increasing students with diverse needs.

Keywords: inclusivity needs, inclusive pedagogy, inclusive teaching practices, engineering pedagogy, inclusive engineering pedagogy, inclusive engineering, engineering teaching practices

Introduction

Returning to the classroom has been a difficult adjustment since COVID-19 for teachers and students alike, resulting in increased mental health issues in college students; particularly, issues such as depression, anxiety, and suicidal ideation (Ebben, 2021). The return to in-person study has resulted in a phenomenon where fewer students attend lectures, and it has become increasingly more difficult for students from diverse backgrounds to interact with their professors and engage with them on the course material (Uekusa, 2023). This is more concerning when considering that these students have reduced their engagement with courses post-pandemic, especially checking out materials and viewing recorded lectures (Summers, 2022). Added to the fact that cheating in college courses has substantially increased post-pandemic, it can be assumed that the traditional methods (such as those used before the pandemic) employed in college education are not working for fostering student learning (Jenkins, 2022).

What can be done to solve this issue? Our research suggests that a change in education methods and attitudes will help foster an environment that both encourages and is conducive to learning. Specifically, we will be looking at data collected from previous studies that can create an inclusive pedagogy conducive to education for all engineering students, focusing on those of diverse backgrounds (such as those from low-income families, those of different races, and with varying levels of previous exposure to coursework) and those with disabilities. Identifying patterns and condensing them into methods that are inclusive and beneficial to student learning will highlight essential teaching methods for the engineering classroom.

What is an inclusive pedagogy? We would define it in two parts. "Inclusive" comes from inclusivity and goes beyond opening spaces for students in a classroom. For a classroom to be truly inclusive, students must be encouraged to enter and fill the spaces provided to them (Moriña, 2021). They must be given attention and opportunities to connect with each other and faculty so that they may not be left behind in the classroom. When taught in an engaging, active, and connective environment, students are less likely to drop engineering majors and more likely to graduate with them (Felder, 2018). Pedagogy can be interpreted as simply techniques and methods of teaching that could give students easier access to the information of a course, but that is not enough to ensure classroom competency. Pedagogy must include faculty investment (Moriña, 2021). An instructor must want to connect with their students, incentivize students to experiment with the materials provided to them to find the best way for them to learn, and be an encouraging force in the classroom. Otherwise, students are likely to continue their trend of not attending lectures, and therefore further slip in coursework. Therefore, an inclusive pedagogy will be defined as a technique of teaching that encourages students to be experimentative in their engagement with material, encourages students to be collaborative with other students and their faculty, and encourages students to remain in their line of coursework and take advantage of the space they occupy in the classroom.

As more students with differing needs or lasting effects from the COVID-19 pandemic enter the classroom, it becomes more necessary to create a standard basis for the inclusive engineering classroom. Without the assurance that all students are set up for success, more will choose to drop out of college and refuse the areas of studies they are not able to grasp. There is a gap in effective pedagogies in engineering fields, especially. Giving educators an effective, researched method and philosophy with which to teach their classroom may help close the gap in engineering inclusivity.

Especially post-pandemic, fostering an interpersonal relationship between faculty and students is necessary for ensuring student success in all fields, and engineering could use a shift in paradigm towards this method. (Vaterlaus, 2021). Inclusive pedagogies have been used in education in multiple different areas and times (Compayré, 1889); however, its adoption in engineering has been relatively new. Inclusive pedagogies have been found to be effective in several disciplines (including engineering) and due to the increasing enrollment of students with diverse backgrounds in engineering, incorporating inclusive pedagogies in engineering is a requirement. Modern engineering pedagogy must incentivize students to interact with faculty, welcome student differences, accommodate for student mental health, and make materials accessible to close the gap. To ensure that our technological advancements continue through our engineers, teaching the next generation in the most successful format possible is paramount to ensuring our continued success.

Methods

For the purposes of this systematic literature review, seven databases were identified: Web of Science, Google Scholar, IEEE Xplore Library, Scopus, ERIC, Wiley Online Library, and Compendex. Through these seven databases, seven search terms were fed: inclusive pedagogy + engineering, inclusive teaching practices + engineering, inclusive classroom approaches + engineering, Inclusive classroom methods + STEM/engineering, Inclusive college classroom + engineering/STEM, Inclusive instruction + STEM/engineering, and Inclusive college education + STEM/engineering. We required that the search be limited to papers published within the last five years (2018-2023) from the time of starting this project. As many papers that discuss engineering courses (such as mathematics, chemistry, biological sciences, physics, etc.) also apply to courses outside of the engineering scope, we included the STEM keyword in our searches. The SLR process and structure/format used in this paper was referred from several existing SLR studies (Borrego, Foster, & Froyd, 2014; Kittur & Islam, 2021; Kittur et al., 2024).

Figure 1 shows the Identification and Screening process, where a total of 2055 papers were initially identified, and after screening for duplicates, 1197 papers were identified by screening. These exclusion criteria were applied to the papers: papers written in a language other than English, papers where the focus was not on the engineering field or courses that would be studied by engineers, and papers where the focus was not on inclusive pedagogy practices. Our inclusion criteria were that the papers must be written in English, must focus on teaching courses centered on engineering or courses studied by engineers, and focus on inclusive pedagogy practices (if the paper mentioned effective teaching skills but not inclusive teaching skills, it was rejected).

After the screening process was complete, 44 papers were synthesized in our literature review. These papers were coded with respect to the specific gaps they overcame (disability, mental health, etc.), the methods they used to be inclusive (individual attention, accessible materials, etc.), and the general focus of the article (faculty improvement, student guidance, etc.). Then, the codes were synthesized into common codes for the articles to place them into the themes, further detailed in Table 4. Upon reading and coding the articles, five themes were identified that the papers fit, with multiple papers fitting multi-theme criteria. In the following section, we discuss these themes.

Preliminary Findings

Table 1 describes the engineering disciplines that the papers included in this review focused on. While more than half of them had no specific focus when it came to STEM fields or engineering, they covered information that appeared in typical engineering classes. This could include math concepts, physics concepts, or general science concepts, just not a focus on them. A few of the papers focused on particular aspects of science that could be included in fields of engineering (such as biology classes for biomedical engineering class), but there were focuses on domains of engineering. Almost 14% of them covered the general engineering domain, but there was a good amount of data on chemical engineering and computer science.

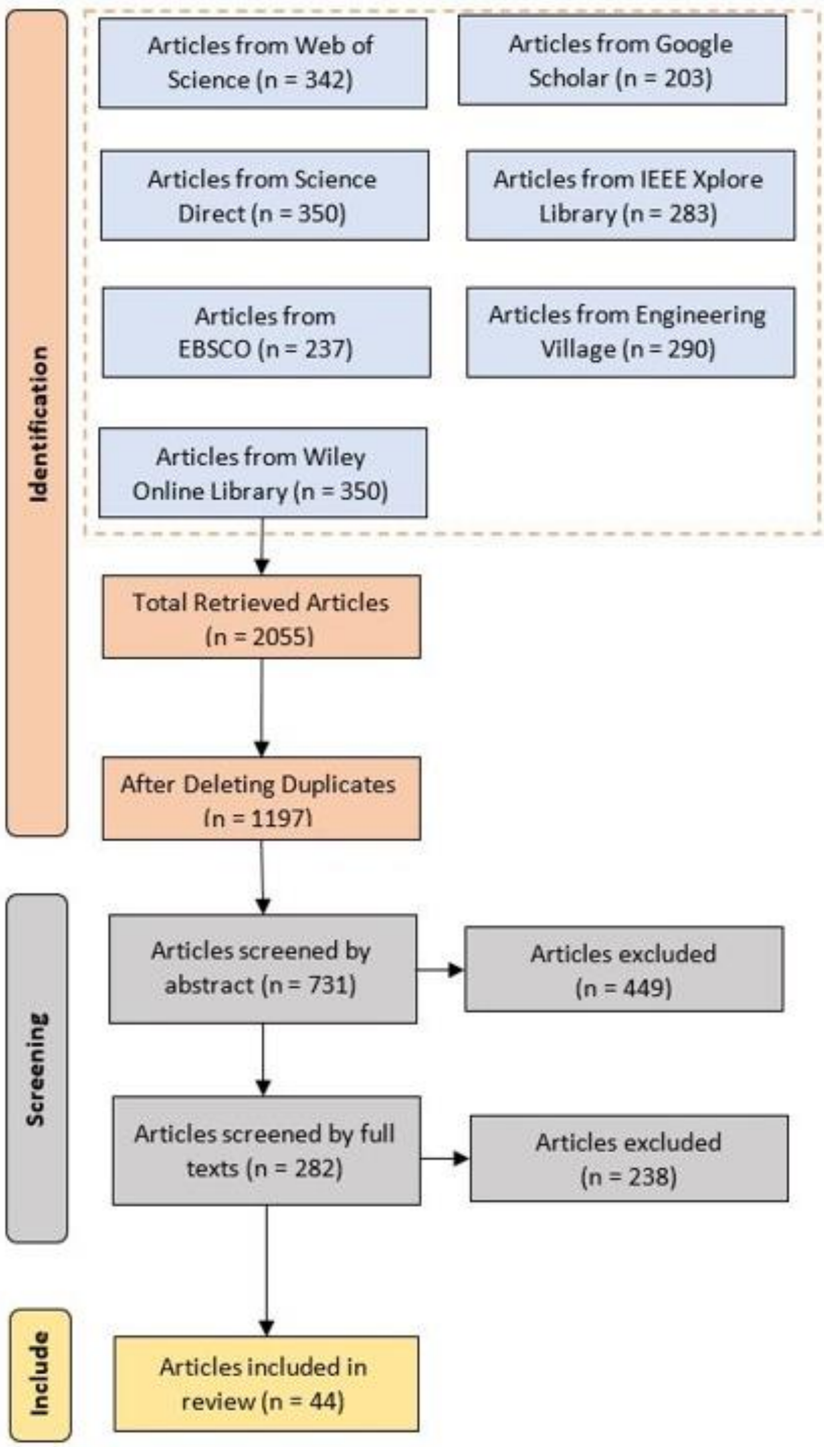

Figure 1. The systematic literature review process

Table 1: Engineering disciplines across the sampled articles

Discipline	***N***	**Percentage (%)**
General STEM	23	52.27
General Engineering	6	13.64
Chemical Engineering	4	9.09
Computer Science	4	9.09
Electrical Engineering	3	6.82
Software Engineering	2	4.55
Biology	2	4.55
Mathematics	2	4.55
Civil Engineering	1	2.27
Environmental Engineering	1	2.27
Geoscience	1	2.27
Cybersecurity	1	2.27
Forensic Science	1	2.27
Physics	1	2.27

Table 2 describes the country affiliation of the first authors by included papers, revealing a spread of interest across the globe. The vast majority of the papers are affiliated with the United States (around 64%), but the other papers are spread throughout Asia, Europe, the rest of North America, and South America. 6.82% of the papers came from Russia, and another 4.55% of papers came from the United Kingdom. This demonstrates that the interest in inclusive engineering pedagogy is not limited to the United States, as many other countries are also studying the framework and trying to apply it to their own education system.

Table 2: First Author's Country across the sampled articles

Country	***N***	**Percentage**
United States of America	28	63.64
Russia	3	6.82
United Kingdom	2	4.55
Australia	1	2.27
Canada	1	2.27
Columbia	1	2.27
Ecuador	1	2.27
Finland	1	2.27
Hong Kong	1	2.27
India	1	2.27
Malaysia	1	2.27
Mexico	1	2.27
Philippines	1	2.27
Slovenia	1	2.27

Table 3 shows the demographics of the papers included in this SLR, including their framework, data collection methods, and data analysis methods. As is clear, there are multiple forms of interest in inclusive engineering pedagogy, and multiple authors are interested in creating a framework and ensuring marginalized students have an accessible space in the field.

Table 3. Research design, data collection, and data analysis across the sampled articles

Research Design	Data Collection	Data Analysis	*N*
Qualitative	Interview	Thematic Analysis	13
Meta-analysis/Literature Review	Identification, Screening, Synthesis	Thematic Analysis	7
Quantitative	Survey	Regression Analysis	6
Conceptual	Author Experiences	Intuitive Analysis	5
Qualitative	Case Study	Comparison/Intuitive	5
Mixed Methods	Survey + Interview	Thematic Analysis	4
Qualitative	Survey	Thematic Analysis	4

Themes

In this section we present the five themes that emerged from the synthesis of the forty-four articles. For every theme, we provide a detailed description of each theme, exemplar studies that closely relate to the theme (two if the theme contains ten or more papers, one if it contains under ten), research limitations, and practice implications. Table 4 describes the themes and the common codes identified for them.

Table 4. Themes, description, associated codes and number of articles

Theme	Description	Common Codes	N
Using Identity to Foster Engineering Connections	Connecting student identities to the engineering concepts they are learning helps them connect intrinsically to the material	Inclusion through representation and attention, fostering engineering interests in students	11
Using Technology to Spread Inclusivity	Technology in the classroom give students more choice in how they understand the material and more accommodations for disabilities	Overcoming disabilities, tactile learning, including technology in the classroom	18
Including Student Interests in Engineering	Connecting student interests to the engineering concepts they are learning helps them connect intrinsically to the material	Fostering engineering interests in students, inclusion through representation and attention, personalizing the engineering journey	8
Active Learning Skill Development for Marginalized Students	Active learning in engineering courses allows marginalized students to develop career	Active learning in the classroom, social diversity, engineering skill development	7

	skills they would not otherwise get the chance to develop		
Inclusivity Pitfalls and Future	Current engineering pedagogy has several pitfalls when it comes to inclusivity, and there are ways to fix the gaps	Faculty training, framework restructuring, inclusivity failures	15

Theme 1: Using Identity to Foster Engineering Connections

Eleven papers were identified during this study that discussed the involvement of student identities in the classroom and their ties to student engineering connections. These papers demonstrated that underrepresented students (such as women, racial minorities, low-income students, mentally ill students, and LGBTQIA+ students) face greater difficulties compared to overrepresented students when it comes to forging engineering connections, and so need additional thought when it comes to including them in the standard classroom. They describe a method to assist them which involves connecting their identities as people with their identities as engineers, as it makes them more enthusiastic to participate in engineering and therefore helps them perform better.

Four of the papers showed a marked improvement in underrepresented student's performance when those students were given representation in the form of discussing or showing an engineer similar to their identity, either in the form of online platforms with diverse avatars of engineers or guest speakers (Casey, E. et al, 2023; Gunjan Tomar & Vineeta Garg, 2021; Good, J. J. et al., 2020; Aguirre-Muñoz, Z. et al., 2021). One paper focused on giving students a space to develop their own identity in connection to their career path through reflective journaling (Tran, K., Barrera et al., 2022). Two papers focused on giving students either a space to choose whether to reveal their identities or a safe space to interact with their identities, such as having their cameras off in online spaces or discussing identities in a supportive manner (Mohammed, T. F. et al., 2021; von Vacano, C. et al., 2022). One paper discussed how underrepresented students connect better with a human centered approach to engineering problems (Rodriguez, S. L. et. al., 2020). Three papers discussed the importance of focusing learning on the skills groups of students need to acquire based on the content (Nasri, N. et al., 2021; Scutt, H.I. et al., 2013; Furner, J. M., & Duffy, M. L, 2022). In general, the papers cover the importance of focusing teaching the students present as opposed to a general body of students, as they require representation, space to create their engineering identity in the classroom, a safe space to interact with their identity as they wish, a human perspective on engineering problems, and instruction catered to their intelligence.

Exemplar Study #1

Over the course of the semester, 11 cultural capitals were identified in the journals of students taking Supplemental Instructional courses: aspirational, attainment, navigational, perseverant, resistance, familial, filial piety, first generation, social, community, and spiritual (Tran et al., 2022). Aspirational and attainment capitals referred to student drive to further their goals or achieve them; navigational, perseverant, and resistance capitals referred to student drive to navigate and persevere through learning and reject opposing stereotypes; familial, filial piety, and first generation capitals referred to student drive influenced by family ties or being the first in their line to attend college; social, community consciousness, and spiritual capitals referred to student drive influenced by factors outside of themselves and their family.

There were no major differences in the way students navigated college or how students developed their goals, but students in the SI courses were the only students to express resistance capitals, as well as being the ones to place more emphasis on community-based capitals (social and community consciousness). This implies that classes that focus on overcoming student difficulties makes them more aware of or more willing to engage with external factors that affect their learning, such as social support or overcoming impeding factors.

In the physics labs and SI courses, around 68% and 71% of them respectively expressed the aspirational capital, suggesting that minority students in STEM set out to achieve a personal goal, and tying this to their engineering identity could help them align those goals with their roles as engineers. Navigational capital was expressed by 74% and 62% of students in lab and SI courses respectively, suggesting that minority students actively take note of and use resources offered to them, and providing these could help them develop their identities as engineers. Of the other cultural capitals expressed, these were the most prevalent, although other student influences should be allowed into the classroom to let students build their own connections.

Exemplar Study #2

In this study, students participated in E2 activities, where language was taught alongside scientific concepts. The results showed significantly more performance growth in students that participated in these activities than it did for students in the control group, and more growth in the creation of their engineering identity (Aguirre-Muñoz et al., 2021). This implies that giving students knowledge on their terms and scaffolding what they learn helps them connect more with the material than the typical format. For students in kindergarten to second grade, significant positive correlation was observed between Engineering learning and identity, implying that students who understand the material have an easier time seeing themselves in the engineering field. Strong correlations were also found between Engineering learning and technology knowledge.

In the study, first grade girls outnumbered first grade boys in a few classrooms, which may have led to their good performance in the classroom. However, the difference was not significant enough to be noted, nor were the gender differences significant in any aspect of the study. The final conclusion stated that engineering identity, engineering learning, and technology knowledge all benefited from the scaffolded English education, which implies that meeting students on their level of knowledge in all aspects is beneficial for them.

Research Limitations

There were very few papers discussing the integration of student identities, so future research projects should focus on drawing stronger correlations between the two so that a standard can be achieved to connect students with their chosen majors. There are many studies on how students benefit from representation in the classroom through digital and physical mediums, so methods such as journaling in the classroom or having open discussions in the classroom about student choices in STEM and reasons for being there should be investigated. The effects of blocked out discussion time could be rich in data for this subject.

Additionally, ways to allow students' choice in the classroom to hide or share their identities should be explored, as giving students a safe space to exist in a classroom may allow them a stronger connection to the major. It is easier on Zoom, as was discussed, but methods that allow students to engage with the classroom content anonymously in person and online should be studied in relation to creating a stronger engineering identity, as there may be a stronger benefit and a standard to ensure students feel safe being connected.

Additional research should be done on finding a standard for making an accessible human-centered engineering education approach. Underrepresented students take well to that teaching approach but standardizing it for all forms of underrepresented students will be helpful for the general inclusive classroom. Additionally, the effects of such an approach on overrepresented students should be studied to ensure that they are not left behind in favor of underrepresented students.

Finally, a standard for identifying the skills that groups of students need a focus on developing should be found, as cultural roles can often cause students to enter the STEM field at a disadvantage. Research done on what skills minority groups usually need help developing and methods to identify those skills should be a priority going forward to ensure students do not get left behind. Allowing students to access the skills they need to develop will help them form stronger Engineering identities earlier in their academic careers.

Practice Implications

When designing the inclusive classroom, these factors should be kept in mind:

1. Underrepresented students must see others with their identity in the role of an engineer to feel welcome in the STEM space.
2. Underrepresented students must have time and freedom to engage with their identities as engineers in the classroom to solidify their engineering identity.
3. Underrepresented students must have the choice to engage or not engage with instruction in class so they may feel safe and welcome in the space.
4. Underrepresented students must have their skill-development needs acknowledged and addressed so they may be at the same level as their overrepresented peers.
5. Underrepresented students must be given a human-centered approach to engineering problem solving.

During the design process, be sure to create spaces for underrepresented engineers to be present. Some suggestions for doing this can be to invite guest speakers with an underrepresented identity to speak about their role as an engineer and their journey towards achieving that role, to show videos in classrooms where underrepresented identities do work in the engineering field, to provide platforms for education where underrepresented models deliver the information or act in an engineering role, etc. It is important that the students see themselves in the physical role of an engineer in a positive light, so that they may also see themselves in that role (Casey et al., 2023).

Having in-class discussions in small and large groups could be greatly beneficial for students, especially when tackling the question of what makes an engineer and why they want to be one. However, it is important to emphasize that students have a choice to participate as much as they would like. For example, White students find it easier to be in online classes with their cameras on compared to Latinx students as Latinx students have more concerns about having family in the background of their videos and the possibility of being embarrassed by them (Mohammed, T. F. et. al., 2021). It is an unfortunate reality that underrepresented students face some resistance in the form of stereotypes and discrimination, so giving students anonymity in the classroom and the ability to choose who they feel safe interacting with can be greatly beneficial to their ability to form a strong engineering identity.

Asking students upfront what areas they feel they need help developing or giving them a skills test at the beginning of class can give instructors more of a feel what each individual class needs focus on and ensure that underrepresented students are not left behind due to not having the opportunity to develop necessary skills for the major. For example, women need more training in spatial skills in the classroom as they have less practice in them compared to men (Scutt, H.I. et al., 2013). Giving that additional focus to them will be influential to developing their engineering identity and keeping them interested in the major.

Giving underrepresented students human-centered engineering issues to solve is necessary to their engineering identity, as they identify with human struggle more than they identify with abstract problems. Learning how they personally can help solve world issues is necessary for them to feel connected to their majors and gives engineering a greater purpose to them. When underrepresented students are given a reason to connect with engineering on a personal level, they are more likely to do so.

Theme 2: Using Technology to Spread Inclusivity

Eighteen papers were identified over the course of this study that discussed the involvement of technology in engineering classrooms and the increased accessibility it brings. The central idea of the UDL (Universal Design for Learning) philosophy is giving students more ways to access content by offering them multiple options so that they may choose how they engage with the classroom. These papers focused on giving students more options to access content in the classroom or making existing classroom content more accessible for them. Underrepresented students (especially those with a disability status) have more trouble accessing content in the classroom, so special considerations are required for them for them to be equally successful as overrepresented students.

Five papers focused on making instruction accessible after lecture or in a form alternative to lectures, either in the form of recorded lectures, instructional video to replace textbook readings, or interactive notes to study with (Pfeifer et al., 2023; Downing et al., 2020; Mohammad et al., 2021; Tomar and Garg 2020; Moon et al., 2012). Three papers focus on the benefit that tactile objects provide to underrepresented students with disabilities, as such objects help them connect better with their learning, help them keep their focus, or are otherwise used to overcome a facet of their disability that makes education difficult for them (Chen et al., 2022; Reynaga-Peña et al., 2019; Love et al., 2022). Six of the papers discuss the multiple other options provided to the UDL framed classroom with the addition of technology, such as digital textbooks, notes, and other such resources that allow students to cater the classroom experience more to their benefit (Pearson et al., 2019; Nasri et al., 2021; Jaramillo-Alcázar et al., 2018; Ndubuisi and Slotta, 2021; Xia et al., 2022; Ndubuisi and Slotta, 2021). Four of the papers discuss the use of technology in the classroom to overcome various disabilities, thus expanding the ability to learn to a greater number of students and becoming more inclusive of them (Love et al., 2022; Contreras-Ortiz et al., 2023; Oreshkina & Safonova, 2023; Oreshkina & Safonova, 2022). In general, these papers cover the importance of integrating technology into the classroom and using it to increase the options students have when learning.

Exemplar Study #1

Examining the design elements in this study, the authors found that those with autism mainly have a visual learning style, and so bright colors, animations, multiple pictures, and more realistic images are helpful for their learning (Contreras-Ortiz et al., 2023). Additionally, those with autism are hypersensitive to noise, so soft sounds are more helpful for them. However, some studies find that cartoons are more helpful than realistic images, so it appears to depend on the individual. Progressive difficulty and supervision software can be helpful for those with autism as well and using affirmative words while avoiding negative influences on their learning can be helpful as those with autism are more sensitive to criticism.

Eye tracking software seems to be helpful in understanding how a person with autism perceives certain stimuli, as a software must be designed to be reactive to an autistic person in order to hold their interest. In addition, software must be friendly to its autistic users and reactive to their needs. For example, language-based software that performs text to speech or speech recognition functions are useful. The use of social robots can be especially helpful in teaching those with autism, as is the use of Virtual Reality. They can simulate enough of organic interaction that they are useful without bringing human bias or other issues into a situation that can harm an autistic student.

The biggest issue when designing technology for an autistic student, however, comes from the difficulty in generalizing the symptoms. Because autism is a spectrum, it becomes exceedingly difficult to design one base software that can generalize to all autistic students or to even know how they would react to customization of a software. Additionally, autistic students may reject the use of sensors due to their hypersensitivity in the first place.

Exemplar Study #2

The study discussed multiple methods for hearing impaired students to connect better with the classroom, including assistive listening devices, telecommunication devices, real time captioning software, real time note taking software, and digital captioning (Oreshkina et al., 2023). The study was based under Bloom's Taxonomy, where the learning of these students was assessed under a scaffolded method. The steps students went through in order were knowledge, comprehension, application, analysis, synthesis, and evaluation.

The study applied this learning process to a chemistry course at the university, and after accounting for individual student needs and differences in impairment, compared the scores of non-hearing impaired and hearing impaired students in the classroom. It was found that their achievement rates went from about 70.2% to about 100% after the process was applied, implying that students who had access to technologies to help them understand the material better were as capable in the classroom as non-impaired students were.

Research Limitations

As the studies took care to point out, there is very little information on disabled students in post-grad education, so there should be an emphasis on that group of underrepresented students in further studies on this topic. In that same vein, there is very little information on technologies designed for disabled students in post-grad education that can handle the amount of work and tasks that post-grads undergo, so research should go into developing such technologies for this group to ensure that those with a disability status are not ignored or ostracized from higher education.

There should be more studies performed on the types of resources you can make available to students that are present in lecture, such as ways for students to digitally ask questions of a professor about a topic covered previously or ways to interact with in class notes or worksheets. Especially regarding higher-education students, the effect of these resources should be measured on student grades, and a standard should be created for how professors make these resources available.

The use of tactile objects in the classroom should also be observed further, especially objects that can be manipulated at will for those who are visually impaired or would otherwise benefit from being able to touch the shapes they are touching and being taught to create. The ability to customize the ability to learn in general should be studied on its effect on student grades. In all levels of education, the ability to change shapes, software, and reading methods should be better understood to create a standard from them.

Finally, a standard should be created for technology used to overcome disability, especially when it comes to autism spectrum disorder. Giving faculty a clear guideline on what to provide to their students can help ensure disabled students do not get left behind in the classroom and are given the care and attention they deserve during their academic journey. There exist many tools for visual and auditory impairments, but they should be studied for potential innovations that can make learning a smoother process for the students. When it comes to physical and mental disabilities, there needs to be a more specific standard and more customization and options for students to choose from.

Practice Implications

When designing the inclusive classroom, these factors should be kept in mind:

1. Technology is a tool, not a hindrance, to the UDL philosophy. Provide your students with all available resources.
2. Try to provide tactile objects, visual aids, and hearing aids in demonstrations when you can, as having them available even when you don't need them is better than not having them when you do.
3. Trust your students when they ask for a resource that they feel they need, as there is not yet a standard providing them with what can help them succeed.

With technology, a number of options have opened up for students to experience their academic journey, and any one of them can be useful to them. For example, students who struggle with learning disabilities (such as ADHD) have difficulties encoding lectures the same as students who don't have those disabilities, and would benefit from the ability to access lecture videos later (Pfeifer et al. 2023).A disabled identity is one of the only identities that a person can acquire at any given time, so having those resources available to all students from the start not only provides them with more options, but it also gives them an easier time transitioning should they acquire a disability or find out that they have one. Some students can even have hidden disabilities that they are not aware of and need the resources, so provide them to all your students. It can only be helpful to them to give them your recorded lectures or interactive notes.

Many students may not feel comfortable disclosing their identity unless they need to, so it is possible that you will not always have a heads up if a tactile object is required or live transcription or audio description is required by a student. Having such objects ready from the beginning will be helpful to students as they do not have to lose a day of learning while the materials are acquired and helpful to the instructor, so they do not have to readjust the teaching schedule. For example, students who are legally blind have a more difficult time visualizing shapes and would benefit from software that could 3D print them for them to touch and manipulate (Starcic et al. 2013). It is better to not need it than it is to need it at the last moment.

Many students have disabilities that do not have an existing standard for how they are assisted, and so are their own best judges for how to assist them. It is important to trust your students in general, but especially regarding the resources they need during instruction as they would know best what helps them. There is nothing to be lost by believing your students.

Theme 3: Including Student Interests in Engineering

Eight papers were identified over the course of this study that discussed the involvement of student interests and their involvement in the creation of or strengthening of engineering interest. By using established connections in class materials, students crafted stronger bonds to their identities as engineers and were genuinely interested in engineering. This also gave students an opportunity to feel more included in class and more welcome.

Five papers referred to what are called "Maker" programs, or programs where students are asked to craft projects around key interests of theirs (Martin et al., 2022; Chen et al., 2022; Rushton & King, 2022; Sormunen et al., 2020; Love et al., 2022). Such programs can be especially helpful to students on the autism spectrum, as many have hyper fixations on key interests. Letting them engage with their interests in a classroom space can help them gain an interest in engineering or help them further their existing interest in it (Chen et al., 2022). Another three papers in this group discuss the fostering and maintaining of engineering interests through games or the inclusion of low stakes community interests (Kuchynka et al., 2021; Casey et al., 2023; Machet et al., 2022). In general, these papers discuss how to capitalize on outside interests to create and further engineering interests.

Exemplar Study

This exemplar paper covers an Autism Inclusion Maker Program and its effect on middle school students from three different schools in New York (Martin et al., 2020). The results of the study showed that all students gained more engineering self-efficacy, career interest, and understanding of the EDP through the IDEAS Maker Program, but autistic students showed less improvement than neurotypical students' career interest and science appreciation. The program itself was voluntary, so it is likely that students who already had a special interest in engineering and STEM and were on the autism spectrum self-selected into the course and already had high appreciation for engineering.

However, the program did lead to autistic students having about a 50-100% increase in time interacting in a social manner with others, even if they preferred to interact with other autistic students more than neurotypical students. Students on the spectrum showed great excitement in discussing their Maker Projects with each other. In fact, the students excelled in creating their projects and making them successful.

Research Limitations

Almost all the information that we have on Maker Programs exists for students below college level education. There needs to be a standard created for Maker-like programs for students in college, graduate school, and post-graduate education. There should also be more research on the basic inclusion of student interests in a lecture, either by finding ways to mix content that students like into lecture slides/videos, or by allowing students to teach a subject with their specific interest as a guide.

Additional information on the use of play to learn engineering concepts, either through physical play or virtual games, is required for a full understanding on the topic. Maker programs interest students who are willing to engage with engineering for their special interests or have engineering as a special interest already, but play can introduce the idea of engineering to those who have not had a chance to experience it yet, which can be especially helpful for underrepresented students. A standard for play in education should be created for this purpose.

Practice Implications

When designing the inclusive classroom, these factors should be kept in mind:

1. Monopolizing on student interests is the best way to get students interested in your class. Incorporate existing interests in your classroom so students have a reason to be engaged.
2. Creating student interest is easiest with something students are already interested in and view as fun, so be willing to engage with students on their interests before they are willing to engage with your class.

For students with autism especially, it is important that they be allowed to engage with their special interests in their chosen career as they hyper fixate on what they love and find it difficult to not do so. For your students, too, it is easier to stay focused in a class that they have a reason to engage with than a class that they have no reason to engage with (Chen et al., 2022). Prioritize your students' interests in your classroom. It is the best way to ensure that students keep their interest in engineering through their academic journey.

For students who are not already interested in engineering, it is important to cultivate it soon or they may drop the study entirely. Try incorporating something that they already enjoy, such as a special interest or a form of play that they enjoy. Since they already engage with that, it will be easier for them to engage in the learning side of engineering as well, and they may develop an interest in it while doing so.

Theme 4: Active Learning Skill Development for Marginalized Students

Seven papers were identified over the course of this study that discussed the involvement of active learning and the development of student skills. For students to perform well outside of the educational space and in the job market for engineers, it is essential that they develop skills that will benefit them in the workplace. Having students actively interact with course content gives them a chance to practice these skills rather than passively take in knowledge, allowing them to refine them by the time they enter the job market.

Two of the papers discussed the process of active learning teaching underrepresented students the skill of self-advocacy/efficacy (Pfeifer et al., 2023; Kuchynka et al., 2021). Four of the papers discussed how the process of active learning brings students face to face with issues that they did not know they needed to develop skills to solve (Rodrigez et al., 2020; Theobald et al., 2020, Dewsbery 2019), such as social interaction (Downing et al., 2020). One of the papers discussed how active learning provided a space for direct instructor feedback that students would not otherwise have (Sormunen et al., 2020). In general, these papers discussed the connection between active learning and the development of individual student skills, either by recognizing the need for them or being in a space where the need to develop them became present.

Exemplar Study

This exemplar paper covers the development of engineering self-efficacy among underrepresented high school students due to active learning, and then covers the same research among community college students (Kuchynka et al., 2021). The study operated under the belief that active learning environments could give students adequate exposure to STEM materials, incentive to study STEM through real world application, and promote STEM self-efficacy. The study operated over a four-week period for high schoolers interested in geoscience and a semester-long mentoring program for community college students interested in STEM.
For the high school students, it was found that STEM self-efficacy increased over time as the program went on, and although the community college students' self-efficacy started out strong, it still showed improvement. It was also found that future STEM predictions could be made using the data from the self-efficacy growth, and STEM intentions would usually strengthen over the program. It was also seen, however, that only high school students who believed the program to be helpful would have the beneficial effects, implying that the class must be suited to them to give them the benefits that it should.

Research Limitations

Standards for active learning already exist and are accurate, but a standard for teaching STEM self-efficacy should exist for each engineering discipline, as there is not much research for that specific skill available. It is important that students develop it early in their academic career so that they are able to fend for themselves in their classes moving forward. Additionally, a standard for active learning that challenges the skills students may not have must be developed in such a way as to not make a student too uncomfortable but still push them on some level. Skills such as pushing past anxiety and realizing personal strengths are key to keeping students in the major, so more research must be done to find out how to have students engage with these areas on their own.

Additionally, research on crafting helpful instructor feedback must be done, as there is a level of specificity that students require from their faculty to truly grow. Research into the language used, for example, could help students understand the point better. Research into the balance between highlighting skills and highlighting improvement areas is also necessary, as too much criticism can paralyze a student whereas too much praise can do the same. Balance is key to keeping students motivated in the major.

Practice Implications

When designing the inclusive classroom, these factors should be kept in mind:

1. Active learning is necessary for normal student growth.
2. Faculty must be active in the praise and criticism of their students.
3. Faculty must be active in challenging their students in a healthy manner.

For students to absorb the content they are taught in the classroom, they must engage with it on a fundamental level, and that sometimes means activities or conversations surrounding the topic. Not everyone has the time to do such things outside of class, so it is most beneficial for a student if in class time is taken to teach the students the skills they need inside the classroom with active learning (Downing et al., 2022). Otherwise, students are not guaranteed to develop the skills as not everyone has the opportunity to learn them outside of the classroom.

Also, students must receive praise for their skills, how they engage with them inside the classroom, and constructive criticism where needed. Students cannot be expected to monitor their own self growth to perfection, so those in charge of them must take an active role in their growth. When faculty members see a student performing well or poorly in an area, it is their duty to help the student grow, as it will help them develop their skills most. Underrepresented students especially would benefit from this due to the achievement gaps between them and overrepresented students (Sormunen et al., 2020).

Faculty must also challenge their students by putting them in situations where they learn to speak up for themselves. Self-efficacy is a tool that is necessary for anyone in a workplace, and especially so in the STEM field as self-advocacy is sometimes the only form of advocacy one has as an underrepresented identity. Faculty must provide a safe space for students to be challenged, as not creating that safe space would hinder the student's growth.

Theme 5: Inclusivity Pitfalls and Future

A total of 15 papers were identified for this theme, a number of them relating to research implications discussed in the themes above. On some level, all of the papers highlighted the problems that underrepresented students face in engineering education that are unique to them. In order to make engineering education inclusive and able to treat students equally, the pedagogy must adapt itself to accommodate for these issues and give faculty and students resources to overcome them.

Eight of the papers discussed the lack of standard for inclusive engineering education, either making an effort to provide that standard or highlighting its nonexistence (Scheffler et al., 2019; Dewsbury & Brame, 2019; Farral et al., 2021; Metevier et al., 2022; Lilly et al., 2022; Reddick et al., 2006; Lapital et al., 2021; Rutt & Mumba, 2022). Four of the papers discussed the existing barriers that students face that current engineering techniques have not been able to overcome, such as accessibility or discrimination (Gavrilova et al., 2021; Moon et al., 2021; Scutt et al., 2013; Walden et al., 2013). Three of the papers discussed ways to overcome these issues, either through developing new tools for accessibility or changing the mindset people have towards disability (Reynaga-Peña et al., 2019; Farrell et al., 2017; Lilly et al., 2023). In general, these papers discussed the greater issues with inclusive engineering education and how to overcome them, along with the need to standardize inclusivity so instructors do not feel lost.

Exemplar Study #1

This exemplar paper covers existing problems in engineering and discusses in general how those problems affect students with marginalized identities (Gavrilova et al., 2021). Students who have disabilities, be they physical or mental, suffer from extra financial costs that other students do not, and therefore are at a disadvantage due to their financial situations and the lack of resources they must put them on a level playing field with other, non-disabled students. Additionally, there are fewer existing resources for disabled students in Engineering compared to students without a disability identity, which gives them an additional barrier to their performance. The paper also discusses the lack of training given to faculty in higher education in how to educate and interact with disabled students, which leaves them without the faculty advisors or adequate mentor connections they need in the engineering field. As those connections are as important, if not more so, than the material students are given, it is crucial that this is resolved as soon as possible.

The article identifies five main issues for disabled engineering students from student survey responses: the physical environment challenges disabled students face when reaching their classes and interacting with their material, the lack of faculty knowledge and skills in teaching and interacting with disabled students, the difficulty in establishing a good theory-practice relationship for students who cannot interact with the material in the same way as other students, the accessibility issues in assessments faced by students in education, and the general biases that students face from both their peers and faculty members when being educated.

Exemplar Study #2

This exemplar paper discusses the creation of a learning framework for inclusive engineering education, and current framework-based issues marginalized groups in engineering face (Farell et al., 2021). The article takes special note of the fact that both the context and environment learning occur in are important to proper learning, so they must be given proper consideration. In particular, the article discusses issues with elitism, the separation of social and technical engineering issues, and hidden engineering curriculum.

STEM education emphasizes the idea that faculty are the experts who give information to empty vessel students, which causes faculty to view students as under them and less like individuals and more like blank canvases of learning. This elitism also causes engineering faculty to view education as consisting of certain universal truths and to value the methods of understanding over the context of understanding and how the concepts they teach get put into practice. Additionally, separating and devaluing the liberal arts makes STEM faculty teach students that technical skills are to be valued over skills like critical thinking and social responsibility.

The separation of technical and social fields turns engineering into a politics-free-zone, which removes the politics of understanding other marginalized identities and accepting them as a part of humanity and the engineering sphere. It also removes personal identity from the classroom, and devalues work done to assimilate marginalized identities into STEM. Engineering also has the issue of validating inequalities by explaining them as skill discrepancies and not social inequity.

Engineering also contains a "hidden curriculum" that enforces ideas of a typical engineer and an outlier. The history of engineering values whiteness, masculinity, and heteronormativity, and the existence of previously stated issues undoes and undervalues work done to adjust the view to be more inclusive. Due to this, marginalized groups are still seen as external to the typical engineering identity, and students who fit the identity are at greater risk of stereotype threat. In a way, social inequity is justified.

Research Limitations

More research is required on the establishment of a framework, as inclusive engineering education is still a new field and not enough research has been performed to say that inclusivity is standardized. In particular, researchers should explore faculty training methods that reduce existing stigmas and make faculty aware of bias in learning materials. Standardized workshops that teach faculty how to communicate with and accommodate marginalized students should be created so educators have the correct tools to ensure inclusivity. More research should be done on the accuracy of faculty identifying and accommodating materials that contain the hidden curriculum of engineering, and materials/workshops should be created in response to fill in the gaps.

Additionally, more research should be done on materials and accessible classroom layouts that help disabled engineering students interact with and learn their material on the same level as students without a disability identity. A standard should be researched for the number of accessible materials in a classroom and the types of accessible materials. Several materials are already being researched, such as audio descriptive platforms (Reynaga-Peña et al., 2019), but more options should be found for various forms of disability.

Practice Implications

When designing the inclusive classroom instructors, should keep these in mind:

1. Be aware of abled-student-dominance in the classroom and provide alternatives.
2. Be sure to include technology in classrooms.
3. Be sure to interact with underrepresented students and overrepresented students equally and create spaces for them to interact with each other.
4. Design the classroom with accessibility in mind.

As most engineering students are sighted, it is easy to create materials that rely on sight for students and expect them to be able to interact with them normally. However, not every engineering student is sighted, and some may gain a disability status related to sight over time. It is essential to the inclusive classroom that instructors are aware of and create alternatives for materials made for sighted students, as it will allow them to be ready for blind students from the first day of class (Moon et al., 2012). In the same vein, other disabilities, such as hearing loss or mobility issues, should be considered and accounted for so they are accessible from day one of the classroom.

In many ways, technology can solve these issues by providing audio descriptions or being used to create tactile replacements for objects, so do not discourage its usage in your classroom. If you do not already have an accommodation in place, allow students to accommodate themselves using technology and leave the space open for them to do so discreetly. Every student requires different things, so trust them to accommodate for themselves.

Mentorship is essential to the student learning process, and it helps create a sense of belonging in the classroom for those who may otherwise struggle to feel accepted. However, students also rely on each other and peer-interactions for a sense of belonging (Dewsbury & Brame, 2019). Be sure to facilitate classroom conversations in safe spaces and encourage students to interact, preferably equally between under- and overrepresented groups of students. In this way, you can have an inclusive classroom that your students participate in constructing with you.

Finally, ensure that materials and general class layout are made to be accessible by all students. Having materials in a format that is equally easy to interact with for all students ensures a level playing field and makes it easier to accommodate unforeseen issues that students may face. Due to COVID, multiple methods have already been crafted that help students access learning materials online, so if materials are hard to accommodate physically, involve an online option so students can still engage (Lorico et al. 2021).

Conclusion

While inclusive engineering pedagogy has made strides in improvement, it is still lacking in multiple areas and there is a general lack of standardization and quality control through education. Once enough research is done to create a standard for inclusivity, we can ensure that marginalized students face minimal issues related to mentorship, peer interaction, discrimination, accessibility, and content understanding in the engineering field. We hope that the noted practice implications become education standard and the research gaps noted are filled in future.

The five themes: Using Identity to Foster Engineering Connections, Using Technology to Spread Inclusivity, Including Student Interests in Engineering, Active Learning Skill Development for Marginalized Students, and Inclusivity Pitfalls and Future; have produced several suggestions for how to structure the inclusive classroom. To synthesize:

1. Students must be given space to engage with their identities on their terms and to identify with their identity in an engineering role.
2. Instruction should take a human-centered approach in the inclusive engineering classroom, with student choice and skill-development needs as a priority.
3. Technology is a tool, not a hindrance, to the UDL philosophy. Providing students with all available resources and being prepared to introduce a new resource if a student asks for or needs one should be a priority. Disability accommodation should be present in the classroom from the start.
4. Student interests must be incorporated from the start into the classroom, and students should be encouraged to engage with those interests in class through assignments or group spaces.
5. Active learning is necessary for normal student growth. Faculty must prioritize healthy, supportive, and meaningful interaction with students in class itself.
6. Be aware of abled-student-dominance in the classroom and provide alternatives.
7. Being aware of student differences and creating equal and open space for students to interact with each other must be a priority. Students must be encouraged to see each other as valid in the engineering space and necessary to continued human progress.

With all of these together, it is our hope that this paper is the first step in creating a universal framework for inclusivity in engineering education, and that faculty who read this can use this information for the betterment of not just marginalized engineering students, but all their students. As research tackles the gaps we have identified, we hope that a new inclusive standard can emerge, and inclusive engineering pedagogical practices become more accurate to what students need to be successful.

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