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Understanding engineering identity in K-12 education: A systematic literature review

Blinded Authors

Introduction

Developing the engineering workforce is a high-priority issue on the US agenda, as it plays a crucial role in fostering technological advancements and economic growth (NAE, 2019). It is well-known that engineering identity (EI) is well-formed before middle school (Hachey, 2020). If children are not exposed to engineering education (EE) by that stage, they are more likely to lose interest in science and math, which ultimately leads to a decline in their interest in pursuing engineering (Pantoya, 2015). As high school approaches, if students do not see themselves as potential engineers, the likelihood of them choosing an engineering career becomes very low (Godwin, 2015). Extensive research has consistently shown that this difference in academic identity directly affects their career decisions and significantly contributes to low enrollment in engineering-related professions (Godwin et al., 2016; Hammack et al., 2015; Kaplan et al., 2014).

To address these challenges, it is evident that incorporating EE in early childhood and maintaining it throughout secondary education is crucial (Brophy et al., 2008). By exposing children to engineering concepts early on, we can cultivate a genuine interest in science and math, laying a strong foundation for increasing enrollment and persistence in engineering-related fields (Hachey, 2021), especially in historically marginalized groups. However, studies investigating EI development have predominantly focused on higher education levels, leaving a significant gap in our understanding of how identity formation takes place in the crucial early years of schooling (Capobianco et al., 2012). Closing this research gap is essential to devising targeted interventions that can positively shape students' perceptions and attitudes towards engineering from an early age, thereby fostering a more diverse and inclusive engineering workforce in the future (Miller et al., 2003). To explore this issue, we conducted a Systematic Literature Review (SLR) aiming to address the following research questions:

RQ1: How is engineering identity conceptualized in K-12 education research?

RQ2: What are the different interventions that have been used to cultivate engineering identity in K-12 education?

RQ3: What are the methodologies used in previous research to assess students' engineering identity in K-12 educational settings?

Theoretical Background

Identity in engineering education

Identity is a complex construct that involves multiple dimensions and evolving definitions. Gee (2000) proposed four dimensions of identity to understand what it is to be a “certain kind of person” (p. 100). These dimensions are nature-identity (who we are), institution-identity (the position we occupy), discourse-identity (interactions recognized by others), and affinity-identity (experience with a specific group).

In the academic and professional domains, such as engineering, identity pertains to how individuals perceive themselves in relation to academic values, their sense of belonging in school, how they are regarded by others, and their performance (Osborne & Jones, 2011). In this regard, McLean and colleagues (2020) defined EI as “thinking of oneself as an engineer and being thought of by others as an engineer” (p. 5).

The development of identity is of utmost importance as it profoundly influences the cultivation of interest, engagement, and the process of making informed career decisions (Archer et al., 2010). In fact, it plays a crucial role in influencing the career paths that individuals choose to pursue (Godwin, 2015) and is closely intertwined with workforce development (Teeter et al., 2020).

Engineering identity and participation of underrepresented groups

Broadening participation in engineering aims to increase representation and inclusion of individuals from historically marginalized groups, like women, racial and ethnic minorities, individuals with disabilities, and those from low-income backgrounds (Mau, 2016). Establishing a strong EI among these groups is vital to their engagement and persistence in EE (Mau, 2016). Unique challenges, such as societal stereotypes, lack of role models, and limited access to resources, hinder the development of an EI for these individuals (Lakin et al., 2022). Addressing these obstacles fosters more inclusive engineering learning environments, promoting positive EI for all students regardless of their backgrounds.

Efforts to promote EI and broaden participation involve interventions like mentoring programs, diverse representation in engineering curricula, exposure to role models, and creating inclusive learning environments that value diverse perspectives (Chemers et al., 2011). By recognizing the role of identity in EE and workforce development, a more inclusive and equitable engineering community can be cultivated. These initiatives not only support individual engineers but also contribute to innovation, creativity, and advancements in the field of engineering as a whole (Smith-Doerr et al., 2017).

Engineering identity and diversification among engineering subdisciplines

Understanding the impact of identity on career choices can lead to valuable insights for fostering diversity within engineering subdisciplines (Teeter et al., 2020). For instance, it is understood that women generally prefer caring professions, and in engineering, often gravitate towards life-sciences-related fields, such as biomedical engineering, while their male counterparts show greater interest in physical-sciences-related fields, like computer science

(Burks et al., 2019; Ecklund et al., 2012). By recognizing the influence of identity on these preferences, initiatives can be designed to encourage broader participation and diversity in various engineering domains (Lakin et al., 2022). Building a more diverse engineering workforce among engineering subdisciplines not only enriches the field with different perspectives and talents but also enhances innovation and problem-solving capabilities, leading to a more dynamic engineering community (Smith-Doerr et al., 2017).

Methods

SLRs are gaining popularity in different research fields as being recognized for their methodological rigor (Moher et al., 2015). In this study, we followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) process to ensure the integrity and accountability of the review (Figure 1, Page et. al, 2021).

We searched studies in six databases: PRIMO, Eric, PROQUEST, IEEE, JSTOR, and the Web of Science. The search was carried out on the title and the abstract, restricted to peer-reviewed articles and conference proceedings. The search query used in all databases was:

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("engineering identity") AND ("k 12" OR "elementary school" OR
"middle school" OR "high school" OR “primary” OR “secondary”)
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All searches were conducted between March and April 2023, resulting in a total of n=1229 records. Figure 2 indicates the number of articles found per database. All articles were uploaded into Covidence to facilitate transparency of this SLR (Babineau, 2014).

After removing (n=37) duplicate records and screening the titles and abstracts, we kept 62 studies for initial eligibility analysis. The inclusion criteria for full-text screening required that articles (1) reported results about K-12 environments, (2) reported an intervention or described an instrument to measure EI, (3) were written in English, and (4) reported empirical studies. We excluded articles (1) that did not match all of the inclusion criteria, and (2) with no full-text available. After a full-text review of the eligible records, n=35 were excluded, and the final manuscripts included for the study were n=27.

Prior to data extraction, the research team created a data extraction form, which was specifically tailored to align with the research questions of the study. An example of an item in the form is "Theories that conceptualize EI." Using this form, each article underwent analysis by one researcher and was then reviewed by another researcher to ensure consensus.

Results and Discussion

Out of the n=27 studies extracted, n=25 were conducted in the United States and two in Turkey. Among these, n=21 studies were peer-reviewed articles, while six were conference proceedings. Figure 3 presents a visual representation of the authors' network within the corpus.

Author networks offer insights into collaboration patterns among researchers, identify expert clusters and influencers, and uncover hidden interdisciplinary connections.

Conceptualization of EI in K-12 education research

During the exploration of the conceptualization of EI, the corpus encompassed a rich array of theories. Notably, "Situated Identity" and "Social Cognitive Career Theory" emerged as the most prominent, with each theory being referenced three and two times, respectively.

Beyond these theories, several other frameworks and perspectives were considered. "Communities of Practice" appeared three times, while "Feminism," the "Ecological system theory," and "Altruistic engineering" each made two appearances.

Furthermore, other theories were utilized once, including the "Framework for Quality K-12 Engineering Education," "Socioscientific Issues framework," "Sense of Self and identity framework," "Epistemic Practices of Engineering," "Lens of possible selves," "Emergent engineering identities," "Engineering activity frames," "Goal congruity theory," "Identity interference," "Agency and structure dynamics," "Sociocultural theory," "Systemic functional linguistics," and "Expectancy-value theory."

Regarding the measurement of EI, Table 1 summarizes the constructs used to assess it.

The array of theories employed in the corpus illustrates the complex nature of the EI construct. Situated identity emerges as the foremost, emphasizing how our identities are molded by specific sociocultural contexts. Additionally, self-efficacy, engineering aspirations, and performance stand out as pivotal constructs to assess EI. Furthermore, the emphasis on communities of practice and altruism engineering describes the value of aspiring to contribute to the greater good and tackle societal challenges through engineering.

Interventions to cultivate EI in K-12 education

In all studies, the interventions were implemented face-to-face, with 14 studies conducted in informal settings such as camps and afterschool programs and 13 in formal settings such as classrooms. The distribution of grade levels and the length of interventions are depicted in Figures 4 and 5, respectively. Moreover, a significant proportion of the target population, constituting 37% of the corpus, represented historically marginalized groups, including African American, Native American, LatinX, Girls/Women, and LGBTQ+ students.

The interventions within the corpus showcased a diverse array of pedagogies, with inquiry-based learning (IBL), engineering design process (EDP), and project-based learning (PBL) emerging as the most prevalent approaches (Figure 6).

The importance of student-centered pedagogies in EE is evident, with IBL, PBL, and EDP being the most commonly employed approaches. This highlights EE's recognition of the value of involving students in practical, problem-solving experiences to foster their understanding and passion for engineering concepts. Furthermore, there is a significant emphasis on EI development at elementary levels, which aligns with existing literature underscoring the critical role of early education in shaping students' identities (Hachey, 2021). Lastly, the preference for sustained interventions lasting longer than a month indicates that identity formation is an ongoing process that requires significant time and that evolves over time.

Methodologies used to assess students' EI in K-12 education

Quantitative research design took precedence, with n=11 studies employing this approach. Validated instruments used in the quantitative studies are presented in Table 2.

In addition, some instruments were developed in the quantitative studies adapting scales used in the following studies and tools:

- Pathways to Engineering project (Cardella et al., 2013) which is also based on SCCT
- Engineering Identity Development Scale (Capobianco et al., 2012)
- Pittsburgh Freshman Engineering Attitudes Survey (Besterfield-Sacre & Wolfe, 2005)
- Technological Problem-Solving Survey (Wu et al., 1996)
- Longitudinal Assessment of Engineering Self-efficacy (Pennsylvania State University, nd)
- Values Assessment (Florida Department of Education, nd)
- Tools for the evaluation of motivation-related outcomes of math and science instruction (Karabenick & Maehr, 2007)
- What I Am Like and Self-Perception Profile for Children (SPPC) (U.S. Bureau of Labor and Statistics, 2006)

Ten studies adopted a qualitative design. Qualitative data collection methods included interviews (n=10), observations (n=7), artifacts (n=4), videotaping (n=4), and open-ended surveys (n=2). Six studies utilized a mixed-methods approach.

The findings show that both qualitative and quantitative research designs have been used to study EI. However, it would be valuable to explore how the results of these interventions evolve over time on a longitudinal basis, especially in terms of their practical implications.

Significance

Our findings provide useful implications, as they reveal that EI is a negotiated process requiring continuous development from early childhood throughout the years. Almost half of the studies focused solely on elementary levels, with most interventions lasting less than a year. To truly grasp the evolution of EI over time, we suggest researchers adopt more longitudinal research approaches. Besides, a substantial proportion of the studies in the corpus targeted historically marginalized groups, underscoring the research community's commitment to fostering diverse and inclusive participation in engineering. Future research should explore the relationships between EI development in K-12 and engineering persistence in higher education and in professions. Exploring these relationships is pivotal in devising strategies to inspire and retain more students in engineering disciplines.

References

Archer, L., DeWitt, J., Osborne, J., Dillon, J., Willis, B., & Wong, B. (2010). “Doing” science versus “being” a scientist: Examining 10/11‐year‐old schoolchildren's constructions of science through the lens of identity. Science Education, 94(4), 617-639.

Babineau, J. (2014). Product review: Covidence (systematic review software). Journal of the Canadian Health Libraries Association/Journal de l'Association des bibliothèques de la santé du Canada, 35(2), 68-71.

Bassok, D., Latham, S., & Rorem, A. (2016). Is kindergarten the new first grade?. AERA Open. Retrieved from: https://journals.sagep ub.com/doi/full/10.1177/2332858415616358

Besterfield-Sacre, M., Atman, C., & Shuman, L. J. (2016). Pittsburgh freshman engineering attitudes survey.

Brophy, S., Klein, S., Portsmore, M., & Rogers, C. (2008). Advancing engineering education in P‐12 classrooms. Journal of Engineering Education, 97(3), 369-387.

Burks, G., Clancy, K. B. H., Hunter, C. D., & Amos, J. R. (2019). Impact of Ethics and Social Awareness Curriculum on the Engineering Identity Formation of High School Girls. Education Sciences, 9(4), 250. https://doi.org/10.3390/educsci9040250

Capobianco, B. M., French, B. F., & Diefes‐Du, H. A. (2012). Engineering identity development among pre‐adolescent learners. Journal of Engineering Education, 101(4), 698-716.

Cardella, M. E., Wolsky, M., Paulsen, C. A., & Jones, T. R. (2013, June). Informal pathways to engineering. In 2013 ASEE Annual Conference & Exposition (pp. 23-747).

Chemers, M. M., Zurbriggen, E. L., Syed, M., Goza, B. K., & Bearman, S. (2011). The role of efficacy and identity in science career commitment among underrepresented minority students. Journal of Social Issues, 67(3), 469-491.

Dyehouse, M., Yoon, S. Y., Lucietto, A., & Diefes-Dux, H. (2012). The effects of an engineering teacher professional development program on elementary students' science/engineering content knowledge and engineering identity.

Ecklund, E. H., Lincoln, A. E., & Tansey, C. (2012). Gender segregation in elite academic science. Gender & Society, 26(5), 693-717.

Gee, J. P. (2000). Chapter 3: Identity as an analytic lens for research in education. Review of research in education, 25(1), 99-125.

Godwin, A., Potvin, G., Hazari, Z., & Lock, R. (2016). Identity, critical agency, and engineering: An affective model for predicting engineering as a career choice. Journal of engineering Education, 105(2), 312-340.

Godwin, A., Sonnert, G., & Sadler, P. M. (2015, June). The influence of out-of-school high school experiences on engineering identities and career choice. In 2015 ASEE Annual Conference & Exposition (pp. 26-1552).

Hachey, A. C. (2020). Success for all: fostering early childhood STEM identity. Journal of Research in Innovative Teaching & Learning, 13(1), 135-139.

Hachey, A. C., An, S. A., & Golding, D. E. (2021). Nurturing kindergarteners' early STEM academic identity through makerspace pedagogy. Early Childhood Education Journal, 1-11.

Hammack, R., Ivey, T. A., Utley, J., & High, K. A. (2015). Effect of an engineering camp on students' perceptions of engineering and technology. Journal of Pre-College Engineering Ed

Hazari, Z., Sonnert, G., Sadler, P. M., & Shanahan, M. C. (2010). Connecting high school physics experiences, outcome expectations, physics identity, and physics career choice: A gender study. Journal of research in science teaching, 47(8), 978-1003.

Kaplan, A., Sinai, M., & Flum, H. (2014). Design-based interventions for promoting students' identity exploration within the school curriculum. In Motivational interventions (pp. 243-291). Emerald Group Publishing Limited.ucation Research (J-PEER), 5(2), 2.

Karabenick, S. A., & Maehr, M. L. (2007). Tools for the evaluation of motivation-related outcomes of math and science instruction: Final report to the national science foundation. Ann Arbor, MI: Motivation Assessment Project.

Knight, M., & Cunningham, C. (2004, June). Draw an engineer test (DAET): Development of a tool to investigate students' ideas about engineers and engineering. In ASEE annual conference and exposition (Vol. 19).

Lakin, J., Mastrogiovanni, M., Davis, E., Marghitu, D., & Davis, V. (2022). " It makes me wanna go out and help people": Enhancing African American Youth's Perceptions of Engineering. Journal of Women and Minorities in Science and Engineering, 28(1).

Markus, H., & Nurius, P. (1986). Possible selves. American psychologist, 41(9), 954.

Mau, W. C. J. (2016). Characteristics of US Students That Pursued a STEM Major and Factors That Predicted Their Persistence in Degree Completion. Universal Journal of Educational Research, 4(6), 1495-1500.

McLean, M., Nation, J. M., Spina, A., Susko, T., Harlow, D., & Bianchini, J. (2020). The importance of collaborative design for narrowing the gender gap in engineering: An analysis of engineering identity development in elementary students. Journal of Pre-College Engineering Education Research (J-PEER), 10(2), 2.

Miller, J.A.; Joseph, A.; Langford, G.M.; Fedoroff, N.V.; Natalico, D.S.; Savitz, M.; Simberloff, D. The Science and Engineering Workforce: Realizing Americas Potential; National Science, Board, National Science Foundation: Alexandria, VA, USA, 2003; pp. 3–69

Moher, D., Shamseer, L., Clarke, M., Ghersi, D., Liberati, A., Petticrew, M., ... & Stewart, L. A. (2015). Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. Systematic reviews, 4(1), 1-9.

Moore, T. J., Tank, K. M., Glancy, A. W., & Kersten, J. A. (2015). NGSS and the landscape of engineering in K‐12 state science standards. Journal of Research in Science Teaching, 52(3), 296-318.

National Academy of Engineering. 2018. Understanding the Educational and Career Pathways of Engineers. Washington, DC: The National Academies Press. doi: https://doi.org/10.17226/25284.

National Academies of Engineering. (2019). Understanding the educational and career pathways of engineers. Washington, DC: The National Academies Press. https://doi.org/10.17226/25284.

Osborne, J. W., & Jones, B. D. (2011). Identification with academics and motivation to achieve in school: How the structure of the self influences academic outcomes. Educational Psychology Review, 23, 131-158.

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., … Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. Systematic Reviews, 10(1), 89. https://doi.org/10.1186/s13643-021-01626-4

Pantoya, M. L., Aguirre-Munoz, Z., & Hunt, E. M. (2015). Developing an Engineering Identity in Early Childhood. American Journal of Engineering Education, 6(2), 61–68. ERIC.

Patrick, A. D., Choe, N. H., Martins, L. L., Borrego, M. J., Kendall, M. R., & Seepersad, C. C. (2017, June). A Measure of Affect toward Key Elements of Engineering Professional Practice. In ASEE annual conference & exposition proceedings.

Smith-Doerr, L., Alegria, S. N., & Sacco, T. (2017). How diversity matters in the US science and engineering workforce: A critical review considering integration in teams, fields, and organizational contexts. Engaging Science, Technology, and Society, 3, 139-153.

Talafian, H., Moy, M. K., Woodard, M. A., & Foster, A. N. (2019). STEM identity exploration through an immersive learning environment. Journal for STEM Education Research, 2, 105-127.

Teeter, S. D., Husseini, N. S., & Cole, J. H. (2020). Assessing changes in attitudes toward engineering and biomechanics resulting from a high school outreach event. Journal of Biomechanics, 103, 109683.

Appendix A. Figures

Figure 1. PRISMA process

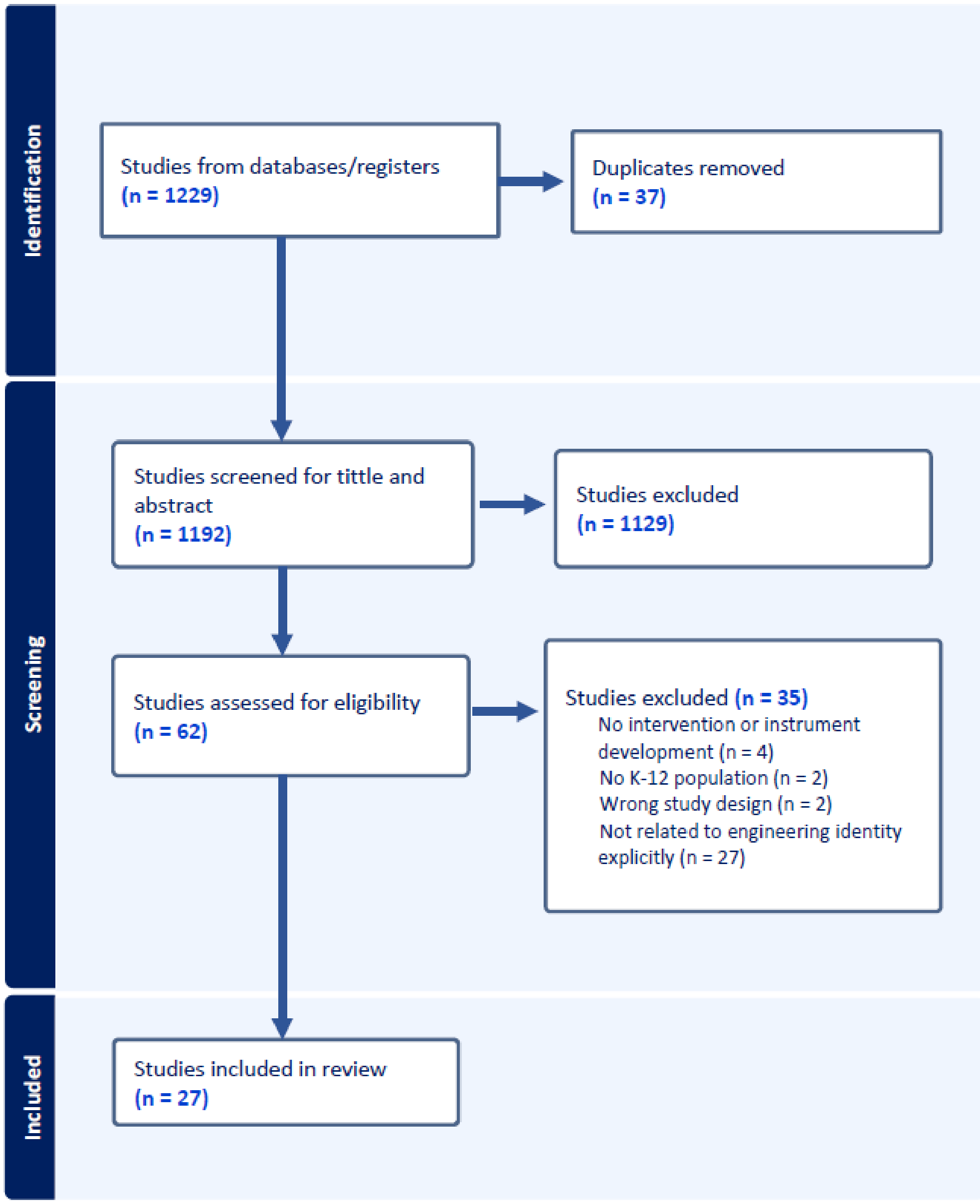


Figure 2. Articles per database

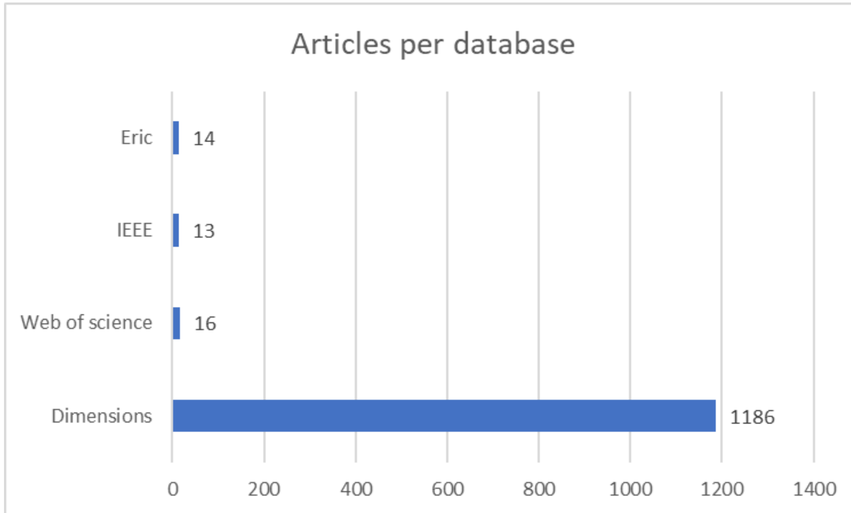


Figure 3. Authors network visualization

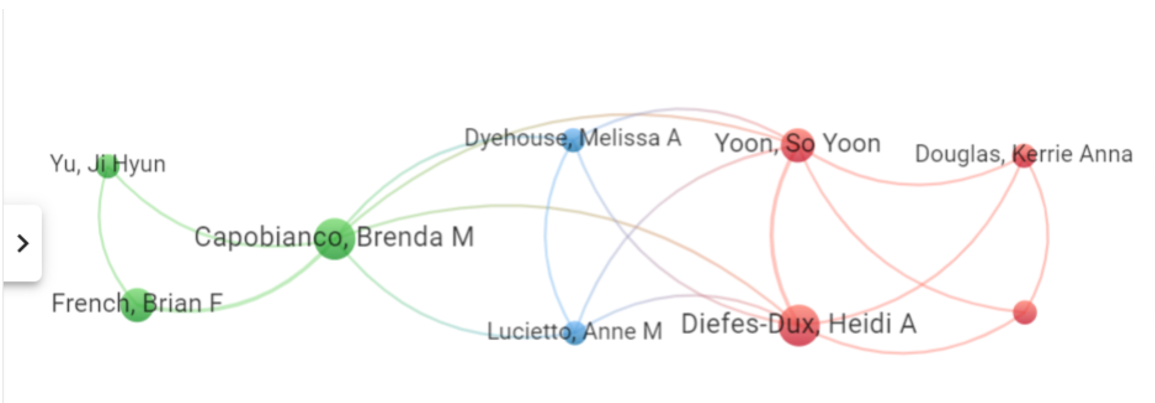


Figure 4. Intervention grade level

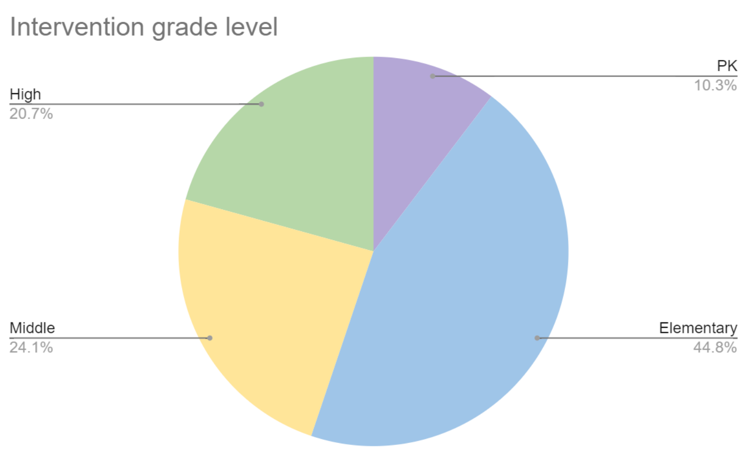


Figure 5. Length of intervention

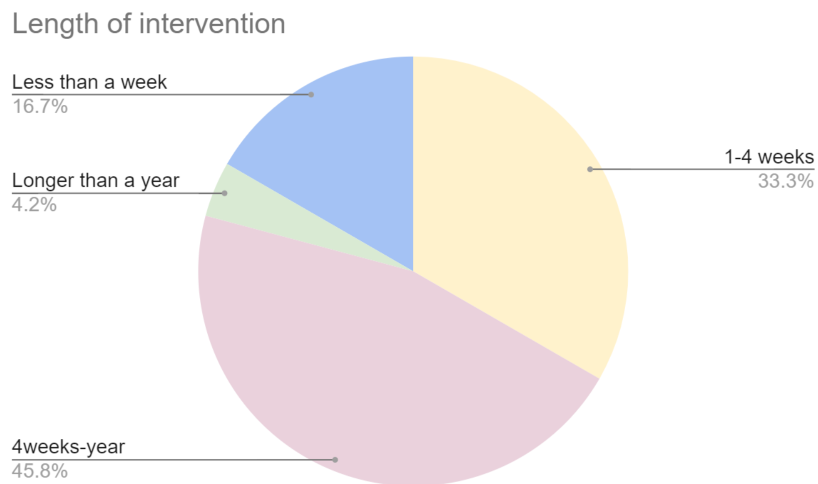
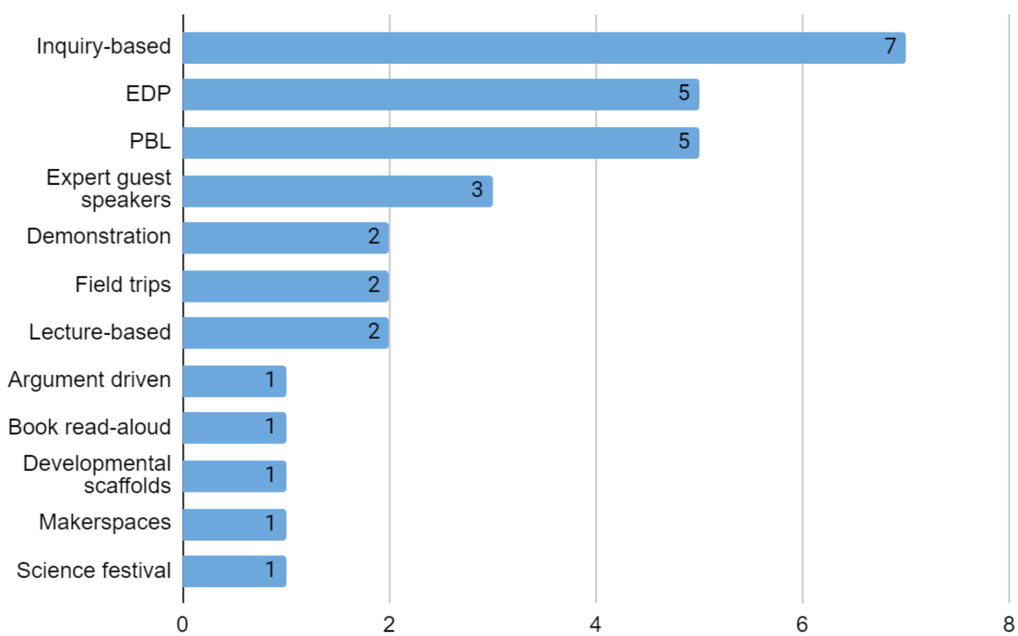


Figure 6. Pedagogies



Appendix B. Tables

Table 1. Constructs to measure EI

Construct	Count
Self-efficacy	5
Academic Identity	4
Engineering Aspirations	4
Performance	3
Agency	2
Career values	2
Engineering understanding	2
Interest	2
Occupational Identity	2
Recognition	2
Role identities	2
School identities	2
Competence	1
Gender	1
Personal interest	1
Social identity	1

Table 2. Quantitative instruments

Instrument	Citation	Count
Engineering Identity Development Scale (EIDS)	(Capobianco, French & Diefes-Dux, 2012)	6
Students Knowledge Tests (SKT)	(Dyehouse et al., 2011)	2
Draw-an-Engineer Test (DAET)	(Knight & Cunningham, 2004)	2
Affect Towards Engineering Professional Practice	(Patrick et al., 2017)	1
Measure of Engineering Identity	(Godwin, 2016)	1