A systematic review of pedagogical tools, learning goals, and participation strategies for high-achieving engineering and STEM students

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Introduction

In recent years, there has been a growing push for more engineering and STEM education at the K-12 level [1]–[3]. This is likely due to a growing gap in the supply and demand of STEM-enabled professionals across different industries, a gap that has been the topic of previous regulatory reports and national calls to action [4]–[6]. As such, researchers continue to more and more look into how to support students learning these critical engineering and STEM skills at an earlier and earlier age as well as the motivations and barriers to entry in the STEM pipelines running through the K-12 school system.

However, how do we best support all students entering their university classes at the same time when some students have a lot of engineering and STEM preparation while others have little to no exposure to STEM? As K-12 students begin to get more and more STEM education at an earlier age, there invariably will be more variability in student preparation once they reach their undergraduate classes. In recent years, one way to address this variability issue has been the use of honors and high-achieving student programs across the United States and globally, with the number of higher education institutions offering honors programs continuing to increase [7]. Yet honors programs and their impact remain understudied in the literature [7].

One of the biggest benefits of having honors and high-achieving student programs at any university is that it allows the university to compete for admitting the best and brightest students [8]. As we increase the amount of variability in student knowledge by building out a more engineering and STEM-focused K-12 pipeline, this will invariably lead to more of a need to support high-achieving students. Honors programs allow universities to compete for these students. And while this is generally a good thing, it has and continues to potentially marginalize and exclude students that don't look or act a certain way based on race or gender [9].

The purpose of this research is to look at multiple questions that arise out of this current reality, by looking at the literature more broadly around honors and high-achieving students in engineering and STEM fields at the undergraduate level. The research aims to explore four different research questions:

(1) Who is the literature defining as high-achieving or honors, and by what criteria is the selection happening?
(2) What skills and learning objectives are being targeted towards honors and high-achieving STEM students throughout the literature?
(3) What educational theories and pedagogical tools have been seen to be successful in high-achieving students?
(4) What motivations do high-achieving engineering students have when transitioning to, and continuing in undergraduate studies?

Background

To fully explore this literature space, we first look at multiple areas of the literature to understand who has traditionally been defined as high-achieving or honors students and what the history of these programs is in STEM fields.

The need for high-achieving STEM students

It is no secret that competent professionals in the United States are needed across STEM fields. Multiple reports in the last few decades have outlined how pressing this need is nationally [4]–[6]. This gap between the highly technical jobs that are required, and the students that have been educated to fill them, impacts many different factors worldwide including the global supply chain as well as national competitiveness at the highest levels.

However, large educational institutions are slow to adapt for several reasons including fear of the unknown as well as resistance to change in general among faculty [10], [11]. This is even more complex in the context of STEM fields, such as engineering, where resistance to change is often the result of limited space in the curriculum [12]. These constraints limit how quickly large educational institutions can adapt to growing needs within a rapidly changing global context.

On the contrary, smaller departments and colleges, such as those of honors programs, may be primed to change and adapt faster than universities on the whole. These programs offer excellent testbeds and demonstrations of how the field as a whole should move.

Roots of high-achieving

The roots of honors programs for high-achieving students can be traced back to academics returning from their studies overseas in Europe [13]. Many of the first programs that resembled current-day honors or high-achieving programs were implemented at Harvard University, the University of Michigan, Princeton University, and Columbia University, with the most current robust version of modern-day honors first appearing at Swarthmore College [13]. The idea of these programs was to create unique learning experiences for students to better showcase and build on their talents.

Fast forward to today, and there is no consensus definition of who honors or high-achieving students are, let alone those who are in STEM fields [14]. The most common metrics are GPA and test scores as predictors of short and long-term academic aptitude [14]. However, we have known for decades and it is well documented that these metrics contain within them bias against underrepresented groups based on factors such as gender and race [15], [16]. This has often left certain groups underrepresented in honors and high-achieving programs as well.

Despite this, there have continued to be more honors programs and colleges aiming to educate high-achieving students across the educational landscape emerging throughout the years [17]. And all of these efforts have led to the questions we are asking in this study, mainly, who are these honors and high-achieving students and how do we best educate them?

Methods

To study these questions, a systematic analysis was used to investigate the literature, and then the results were searched for themes amongst the data.

To collect the literature to use as data for this study, a systematic literature review process was used as outlined by Borrego, Foster, and Froyd [18] who gave the following steps: (1) deciding on the scope and questions of the review, (2) setting how studies will either be included or excluded from the current review, (3) finding where studies are indexed and can be searched, (4) synthesizing all of the papers and findings into results. In the following sections, we overview how each of these steps was accomplished in this literature review.

Keywords and Search Strings

The scope of any literature review is largely dictated by the search terms that are used to collect the data set. In this study, we used three keywords, and associated synonyms, to identify the paper set to be analyzed. The keywords used for the study are outlined in Figure 1.

Figure 1. Keywords used for the current study.

Key Word	**Synonyms**
High-Achieving	*Gifted, Honors, High-Ability, Accelerated Learner, High-Aptitude*
STEM	*Science, Engineering, Engineer*
Undergraduate	*University Student, Transition to College, First-Year*

The three keywords define the scope and purpose of the literature review at hand. The first word, high-achieving, is the population of students that the study aims to learn more about. The second keyword, STEM, defines the areas of study in which we are interested. And finally, undergraduate defines the context in which we are interested, which is students who have completed high school and are either transitioning to university or already enrolled.

We then combined these keywords into search strings and used three databases that are common for engineering and STEM education-related articles [19], [20]. The databases used for this study, along with associated search strings, are in Figure 2 below.

Figure 2. Databases and search strings used for the current study.

Database	Search String	Results
Education Source	TI (((high-achieving) OR (gifted) OR (honors) OR (high-ability) OR (accelerated learner) OR (high-aptitude))) AND TI (((engineering) OR (engineer) OR (science) OR (STEM))) AND AB ((undergraduate) OR (university student) OR (transition to college) OR (first-year)))	29

ERIC	title:("high-achieving" OR "gifted" OR "honors" OR "high-ability" OR "accelerated learner" OR "high-aptitude") AND title:("engineering" OR "engineer" OR "science" OR "STEM") AND abstract:("university student" OR "transition to college" OR "first-year" OR "undergraduate")	20
Compendex and InSpec	(((((high-achieving) OR (gifted) OR (honors) OR (high-ability) OR (accelerated learner) OR (high-aptitude)) WN TI) AND (((engineering) OR (engineer) OR (science) OR (STEM)) WN TI)) AND (((undergraduate) OR (university student) OR (transition to college) OR (first-year)) WN AB))	34

There were modest results from each of the databases, but large enough to encapsulate many of the biggest themes from the literature. Given that there were multiple duplications amongst the three databases, the research team felt that the search was broad enough with the given results. The initial results from the three databases yielded 83 studies to investigate before duplicates or inclusion/exclusion criteria were applied.

Inclusion and exclusion criteria

Once the total dataset was identified, multiple inclusion and exclusion criteria were used to identify only the most pertinent articles to answer the research questions of this study. The criteria used were the following.

(1) The main focus of the paper must be on engineering, science, or STEM students more broadly. While there is important work to be done with students in other fields, our focus was on the STEM classroom.
(2) The paper must have been published in the last twenty years. Given how much high-achieving and honors programs have changed through the years, we thought only getting the research from the last two decades would yield the most useful results.
(3) The paper must be from a peer-reviewed journal or academic conference. We wanted only high-quality studies to be part of the systematic review and felt this criterion would better ensure quality.
(4) The paper must be on or speak to, the pedagogical design, learning outcomes, motivations, or participation of students within a relevant STEM/general honors program, or be defined as high-achieving explicitly.
(5) The paper must be accessible from the Purdue University library system, which is what we were using to conduct the literature review. We felt this was reasonable given the R1 status of Purdue University and the quality of the BIG10 library sharing system.

After applying these inclusion and exclusion criteria to the set of papers, we netted 23 high-quality papers that were ready for analysis.

Data analysis

The dataset was analyzed in two ways. First, the metadata of each paper was looked at to see if there were any interesting findings in terms of common years, authors, or journals that seemed to be publishing research that addressed these questions.

From there, the papers were analyzed for themes or patterns that emerged from the papers. The entire data set was read by one member of the research team, and items that were related to the four research questions were identified. The four categories that items from each of the papers could fall into were as follows: (1) what defines high-achieving students, (2) what are we trying to teach high-achieving students, (3) what kind of classroom interventions have been used for high-achieving students, and (4) what motivates and drives participation of high-achieving students.

Once the entire dataset was read and broken into these four categories, the two researchers both looked at the items and separately grouped them into themes corresponding to the four categories. Once these early patterns and themes were identified by the two researchers, they were consolidated and given descriptions. From there the emergent themes were reviewed and iterated until they were finalized into their current state.

Results

The results section is broken into multiple parts. First, we look at the metadata from the paper set to see if any patterns emerge. From there, we look at themes that emerged related to each of the four research questions.

Who is talking about honors and high-achieving students in the literature?

When looking at the metadata of the papers, there were a few findings based on the dataset. The first is that, in general, the number of papers per year seemed to increase throughout the twenty years, although the increase was modest. The second pattern was that the most published places for the dataset were in the ASEE conference proceedings (11 of 23) and the Frontiers in Education conference proceedings (4 of 23). Beyond these two conferences, there was little pattern in the rest of the publications in the dataset.

Who does the literature define as an honors or high-achieving student?

It appeared that across the dataset, there was no consensus for what a high-achieving or honors student was, but there were many different factors that were consistently used to identify who might be considered a high-achieving student. There were a few themes that seemed to emerge from the data set as a whole.

GPA, test scores, and class rank: The two most common metrics used to identify high-achieving students were GPA [21]–[25] and standardized test scores [21], [23], [25]–[28]. Additionally, many studies used class rank to understand if students were high-achieving compared to their peers [25]–[27]. These three metrics showed up time and again throughout the dataset, which should come as no surprise given that two of these metrics (GPA and test scores) are used in general for university admissions.

Application supplements: Many other less-expected metrics also showed up throughout the dataset that showed creative approaches to identifying high-achieving or honors students. Many of the studies added additional requirements from the student's application package. For example, a few of the studies discussed the use of interviews to identify high-achieving students [23], [27]. One study talked about the use of additional examinations before acceptance as a criterion for high-achieving students in an honors program [27]. There were even a few studies that defined high-achieving students simply as students that participate in an honors program or are enrolled at a high-level STEM college [28], [29]. While overall the studies seemed to rely on the more traditional quantitative metrics, many did use these additional academic requirements as well.

Extra-curricular or STEM activities: One encouraging finding was that many studies also focused on additional extracurricular activities in their definition of high-achieving students. This ranged from looking at students' involvement with STEM or academic-focused groups [30] to focusing in on community service experiences [24]. While these showed up in the data set, they certainly were not the norm as part of the comprehensive list of what defines honors students.

What are we trying to teach high-achieving and honors students?

Multiple themes emerged from the analysis regarding what students are being taught or learning in high-achieving settings.

Strategies for solving complex problems: One theme that continuously showed up was concepts that are related to strategies for students to solve complex problems. Examples of these included studies emphasizing teaching concepts such as creativity [24], [25], reflection [31], systems thinking [25], and approaching a problem from multiple different angles or perspectives [32], [33]. The studies also emphasized expanding the tools students used to solve these complex problems by discussing learning objectives related to topics such as abstraction [34], unstructured problem-solving [25], and more complex classroom tools [35]. These different approaches show that many educators across the literature were concerned with broadening how student approach solving difficult problems.

Broader Perspectives: Adding to this broadening of problem-solving methods, were studies with the goal of providing students themselves with broader perspectives on how STEM fields affect the world around them. This ranged from educators incorporating community work/service in the curriculum [35] to teaching high-achieving students about how their work impacts societal problems [27], [36] and natural environment [24] around them. Thus, the high-achieving and honors curriculum seemed to have a heavy focus on thinking about not only the technical work the students would be doing but how their work influences everything around them.

Interpersonal skills: Finally, the results indicated that the literature has focused on teaching high-achieving students interpersonal skills apart from the more traditional technical skills that are often the focus in STEM contexts. Some of the examples from across the dataset were intrapersonal communication [30], teaming [24], task allocation amongst a group [24], and leadership training and skills [23], [27]. The emphasis on all of these skills was promising to see frequently throughout the dataset.

What types of classroom interventions were proposed by the literature for honors or high-achieving students?

There was a wide range of classroom practices that were suggested by the high-achieving/honors literature, most of which are widely accepted best practices in all classrooms. However, there were a few key themes that showed up time and time again.

Real-world experiences and application: One theme that showed up time and time again across the dataset was real-world, or hands-on, experiences being implemented into the learning design. Many classroom interventions reported adding realistic projects or case studies that are more hands-on or industry related into the course design [34]–[39]. Other studies talked about adding realistic components to a curriculum as a whole rather than just in project work in a particular class [24], [27]. Other studies took this step further into actually interfacing with industry through the use of industry mentors [23] or work-integrated learning where students worked in the field [30]. However it was done, there was a clear emphasis on real-world experiences that seemed prevalent to high-achieving and honors populations.

Bridging topics and disciplines: One interesting finding was the emphasis on learning that was interdisciplinary or that bridged multiple topics together. For example, there were a handful of studies that integrated research methods or writing into courses or curricula for high-achieving students [25], [36], [40]. Other studies discussed how high-achieving students are exposed to, and benefit from, interdisciplinary projects. Some of these projects are more feasible when interdisciplinary faculty are brought together through structures such as Honors Colleges [33], [37].

Added complexity: Many of the studies reported that one of the biggest deviations for high-achieving and honors curricula is the addition of complexity through both how fast the courses move and the inclusion of additional content [23], [24], [26], [36]. However, studies varied in how the complexity was added to the classroom. It ranged from an overlay structure for high-achieving honors students mapped onto existing classes [23], e.g. instructors having additional honors contracts for high-achieving students [37], to having entirely separate honors courses for high-achieving students [27]. Although, the separation of content within the same course did seem to have some reported drawbacks; mainly the concern that non-honors students felt that they were left out of the enriched learning opportunities [34].

What motivates and drives participation for high-achieving and honors students?

Performance seems key, but now always: A few of the studies highlighted that high-achieving and honors students are extremely motivated by performance metrics such as grades or performance against the peers around them [21], [31], [41]. This is especially prominent in high-achieving female students [41]. And while many high-achieving students fear that their grades will suffer from being in harder classes, one study showed that these grades are not only the same as their non-honors counterparts, they are statistically higher [26]. However, there were some exceptions to this throughout the dataset. For example, students with a low socioeconomic status (SES) are likely to focus heavily on economic opportunity in STEM fields and how their work impacts the society around them [42]. While performance is a motivator for many high-achieving or honors students, it is certainly not the only or necessarily the best.

Fostering engineering identity is important: One theme that showed up all across the dataset was the idea of engineering or STEM identity and its importance in motivating and driving participation in high-achieving programs. Many high-achieving or honors students struggle to see themselves as engineers or STEM professionals, and this is especially prominent among students from underrepresented groups or low-SES backgrounds [21], [43]. Some of this identity gap in underrepresented groups is a lack of support external to the classroom and a lack of opportunities as compared to their peers [43]. What seems to help foster identity, and in turn participation, among underrepresented groups is focusing on societal applications [42], support from their local community [21], and opening up the curriculum to more interdisciplinary and non-traditional approaches to engineering [33]. One quote that Omitoyin et al. [21] wrote sums up this idea of how to drive participation and motivation in underrepresented groups is:

> "Therefore, it may be salient to align engineering course content with how students identify engineers: content that more closely aligns with improving the world, helping individuals, and solving problems" [21, p. 14].

Looking to their future careers: Another theme that prevailed was how students seem to have an eye towards their future careers as motivation in their programs. For example, students are most motivated to participate in learning interventions and experiences that would make them more employable in the future [30] or that they have a current interest in [35]. The dataset also described how high-achieving students are more engaged in realistic problems [39] and projects that allow students to engage in problems that require them to work across fields and disciplines [37]. Ultimately, high-achieving students seem to want learning interventions that look like the type of things they will be doing after they leave their undergraduate years.

Discussion

The results illuminated multiple findings that connect to the literature in terms of what we know about learning and high-achieving or honors programs in general. We discuss these findings in light of the broader literature as well as what the ultimate implications for teaching and learning are based on the results.

One of the key themes from whom the studies defined as high-achieving was based on traditional metrics such as GPA, test scores, or class rank. The research has shown that metrics such as GPA and test scores do have some predictive power [44]. However, they come with severe limitations as well, including bias against different groups based on race, gender, and socioeconomic status [15], [16]. This likely leads to, and compounds, the fact that there already are large existing gaps in STEM fields for many of these same students in the first place [45], [46].

This heightened emphasis on GPA and test scores combined with the existing STEM gap results in high-achieving and honors STEM programs being some of the most likely places in academia to have already underrepresented voices missing within their programs. More work and research should go into how high-achieving and honors STEM programs can identify potentially successful students via other nontraditional means such as interviews or extracurricular activities, two practices that we saw in the dataset. Additionally, a better understanding of how these metrics predict success within honors and high-achieving programs should be obtained.

The data did provide insights into motivating and engaging students from underrepresented groups once they are admitted to high-achieving or honors programs. Studies seemed to indicate that motivating students from a diversity of backgrounds requires diverse instruction techniques in high-achieving settings [21], [43]. One of the themes that was present was that students, especially those from underrepresented groups, may be more likely to care about the social applications or the community around them as it pertains to their STEM discipline.

There have previously been calls in the literature alluding to the lack of social awareness in fields such as engineering and the physical sciences [47], [48]. There are also many ways to provide this broader awareness reported throughout the literature. Some options include service learning in the classroom or additional community-focused projects [48], [49]. Our findings indicate a higher emphasis in the STEM classroom on these topics may help to retain, or at a minimum engage, high-achieving/honors students from underrepresented groups in the classroom.

Finally, our results seemed to indicate a simple but resounding truth, that many methods of teaching and learning seem to be able to work across contexts, not just for high-achieving or honors students. Despite a multitude of evidence to the contrary, the belief seems to still propagate that there are distinct learning styles. Study after study shows that there is no concrete evidence that students fall into discrete learning categories [50], [51]. Many of the pedagogies seen in our dataset were all highly accepted practices among the general student populace such as project-based learning [52]–[54], interdisciplinary and multidisciplinary learning interventions [55]–[57], and realistic hands-on interventions [20], [58], [59]. Riener and Willingham [50] said it best when they wrote:

> "So here is the punch line: Students differ in their abilities, interests, and background knowledge, but not in their learning styles. Students may have preferences about how to learn, but no evidence suggests that catering to those preferences will lead to better learning" [50, p. 35].

Our results corroborate this idea. The literature indicates that high-achieving students learn just the same way as any other student.

What are the implications for teaching and learning?

While the results indicate that high-achieving students learn in much the same way as any other students, there are some key findings that would be helpful for practitioners to be mindful of when designing teaching and learning interventions for high-achieving or honors students. This is not because of the learning style of the classroom itself, but more related to whom the classroom consists of, to begin with.

High-achieving or honors students are likely able to be taught at an accelerated pace [26]. This means that the curriculum may have room for additional topics that are important for STEM professionals but often left undertaught such as our themes of *strategies for solving complex* *problems, broadening perspectives,* and *interpersonal skills.* Additionally, students benefit from more *real-world or application-based* learning with *added complexity*. Given that high-achieving students may also be structured together into honors colleges with multiple disciplines, there is also more opportunity for instructors to incorporate pedagogy that *bridges topics and disciplines* in ways that engage these students.

Finally, given that a selection process built on GPA and test scores is likely to introduce significant bias in who is sitting in the seats in a high-achieving setting, which is compounded even more by the participation gaps in STEM fields in general, instructors should pay careful attention to instilling belonging in classroom environments through the use of inclusive pedagogy [46], [60]. Our results indicate that a good starting point for instructors would be to make sure to *foster engineering identity* through pedagogical interventions that focus on aspects that are important to underrepresented groups such as community service or service learning as well as incorporating learning designs that look like students' *future careers*.

Conclusion and Limitations

This study has a few limitations that make it hard to generalize the findings across contexts. First, given the sample size of studies continues to be small, with 23 high-quality studies in the final dataset, more work needs to be done to make the identified findings more concrete for STEM researchers and educators. Additionally, our work is limited by the libraries that were used to compile the results and are heavily from journals situated in the United States. A third limitation is that who is defined as high-achieving differs from study to study, and thus, it came become difficult to get a clear picture of what students are being discussed throughout the literature. A broader literature review may identify additional themes from the literature in new and different contexts.

High-achieving and honors students in STEM are an important piece to the higher education academic landscape. Our evaluation has highlighted that there is still critical work to be done in whom we define as high-achieving in academic contexts and how we help broaden engagement and retention once students are participating in high-achieving programs or contexts. This can be done through the use of more inclusive classroom design as well as focusing on additional student motivators beyond performance, such as service learning or work-integrated learning.

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