The Role of Andragogy in Mechanical Engineering Education

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Abstract

As highlighted by ABET mechanical engineering program accreditation criteria, a goal of an undergraduate mechanical engineering program is to prepare undergraduate students to work professionally in thermal or mechanical systems. Correspondingly, a student's undergraduate experience marks a transition from their formative years as teacher-dependent, full-time students toward an adulthood marked by self-directed learning and full-time employment. To date, undergraduate engineering education literature has oriented on students as young, dependent learners through the use of the term pedagogy to describe techniques and methods of teaching rather than the term andragogy, which refers to educating adult, self-directed learners. A search for the two topics in the Journal for Engineering Education returns 277 articles associated with the term pedagogy compared to 2 for andragogy, for a ratio of over 138:1. For the International Journal of Engineering Education the ratio is 119:1. A similar search of all ASEE conference articles since 1996 returns over 104:1. The initial conclusion of these findings is that the topic of andragogy is less prevalent than pedagogy in engineering education publications. This is problematic considering these two learner orientations bring with them a set of conflicting underlying assumptions regarding the learner themselves, with the pedagogical assumptions less consistent with ABET student outcomes.

The purpose of this paper is to provide undergraduate mechanical engineering educators with a better understanding of how andragogy may play an integral role in the education of undergraduate engineering students. The assumptions associated with andragogy may be better suited to preparing students for the rigors of professional mechanical engineering practice. Using

a single case study methodology, this paper examines the guiding documents of one undergraduate mechanical engineering program including 1) National level engineering education guiding documents, 2) institution-level guiding documents, and 3) department-level mission and vision statements. Results from this case study analysis contrast the applicability of pedagogical and andragogical assumptions in the education of undergraduate mechanical engineers and highlight how the historically pervasive pedagogical assumptions may hinder the development of students into independent, adult learners. The paper concludes by proposing the use of a continuum to view how pedagogy and andragogy apply across the entire undergraduate mechanical engineering experience as we encourage students to develop into adult, self-directed learners prepared for a life of professional engineering practice.

Introduction

At the heart of engineering and engineering design is problem-solving. Engineers apply scientific principles to solve problems and design solutions to improve society. It is the role of engineering educators to best prepare engineering students to possess the skills, knowledge, and attributes necessary to succeed as a problem-solver. Throughout engineering education literature, the term pedagogy is used to describe the methods and techniques used in engineering education. The purpose of this paper is to suggest that the very nature of engineering may be better served by an education approach that also incorporates elements associated with the term andragogy, or the education of adults. This work explores the concept of and andragogy and contrasts it with pedagogy. Then, the paper will examine a case study using the Mechanical Engineering program at West Point to determine if the principles of andragogy would best suit the goals and objectives of the program, as stated in governing documents.

Background

Before discussing andragogy at any length, it is important to review the term pedagogy as a contrast. The term pedagogy is well documented and is described invariably as leading children, from the Greek roots of leading and boy.[1] Watkins and Mortimore add that the term has taken on a greater meaning to describe the 'science of teaching'.[1] However, the root of the term remains the idea that the teacher is an adult and the student is a child and needs to be led.

Andragogy, on the other hand, is a term that is also rooted in the Greek language and means the leading of 'man', or adults.[2] Perhaps no discussion of andragogy is appropriate without the mention of Malcolm Knowles. In the 1970s he wrote on the topic and contrasted how the two theories viewed the learner.[2-3] The greatest difference between the two was the level of dependence the learner had on the teacher. Knowles describes learners as goal-oriented, activity-oriented or learning-oriented. The goal-oriented learner sees learning primarily as a means to an end, either to attain a degree or perhaps a job. An activity-oriented learner seeks learning as a way to accomplish or engage in some desired activity. Finally, a learning-oriented student sees learning as an end in itself and as a way to increase one's mental abilities.[3]

A motivating factor in andragogy literature is the nature of knowledge. Knowles points out that as mankind and technology progress, the turnover of social knowledge is accelerating. Whereas in the past, a person could acquire the knowledge they needed for a lifetime at an early age, the advent of the 20th Century made that concept more and more obsolete.[2] One is reminded of the social tale about fishing. In the story, we are told that if we teach a person to fish they can feed them self for a lifetime. However, this is true only if fishing remains a viable activity for one's lifetime. Metaphorically, andragogy proposes that instead we teach a person to teach them self to fish. The skills developed in learning the process on one's own will be

applicable if fishing is no longer feasible and a person has to teach them self to hunt or raise crops instead for a food source.

Merriam summarizes the assumptions of andragogy into five overall categories.[4] They are:

1. **Concept of the Learner:** The learner is independent and can direct their own learning.
2. **Role of Learner Experiences**: The learner has real-world experiences that they can incorporate into their learning.
3. **Readiness to Learn**: The learner has a need to learn based on the acceleration of social changes discussed above.
4. **Orientation to Learning**: The learner sees an immediate application for the learning they conduct.
5. **Motivation:** The learner is internally, rather than externally motivated.

   An excellent summary of the five categories above and how the assumptions about each category differ in a pedagogical approach compared to an andragogical approach

appears below in Table 1. This table appeared in an online article compared the two approaches.

Table 1: Comparison between Pedagogical and Andragogical Assumptions[5]

Pedagogy vs. Andragogy

	Pedagogical	Andragogical
The Learner	• The learner is dependent upon the instructor for all learning • The teacher/instructor assumes full responsibility for what is taught and how it is learned • The teacher/instructor evaluates learning	• The learner is self-directed • The learner is responsible for his/her own learning • Self-evaluation is characteristic of this approach
Role of the Learner's Experience	• The learner comes to the activity with little experience that could be tapped as a resource for learning • The experience of the instructor is most influential	• The learner brings a greater volume and quality of experience • Adults are a rich resource for one another • Different experiences assure diversity in groups of adults • Experience becomes the source of self-identify
Readiness to Learn	• Students are told what they have to learn in order to advance to the next level of mastery	• Any change is likely to trigger a readiness to learn • The need to know in order to perform more effectively in some aspect of one's life is important • Ability to assess gaps between where one is now and where one wants and needs to be
Orientation to Learning	• Learning is a process of acquiring prescribed subject matter • Content units are sequenced according to the logic of the subject matter	• Learners want to perform a task, solve a problem, live in a more satisfying way • Learning must have relevance to real-life tasks • Learning is organized around life/work situations rather than subject matter units
Motivation for Learning	• Primarily motivated by external pressures, competition for grades, and the consequences of failure	• Internal motivators: self-esteem, recognition, better quality of life, self-confidence, self-actualization

To gain a better understanding of the use of the term andragogy, the authors examined the literature surrounding engineering education and scholarly works. The search returns are certainly telling. A simple search on Google Scholar yields 1,230,000 results for pedagogy

compared to 28,500 for andragogy, or a 43:1 ratio. An examination in the context of engineering education is more telling. The same search of all ASEE conference articles had an even greater disparity, yielding 4,375 returns to just 42, for a 104:1 ratio. Both the Journal and International Journal for Engineering Education revealed ratios of 138:1 and 119:1, respectively. Clearly, the term pedagogy is much more commonly used in the context of educating engineers. Figure 1 shows the ratio of pedagogical- to andragogical-related publications for various publication outlets.

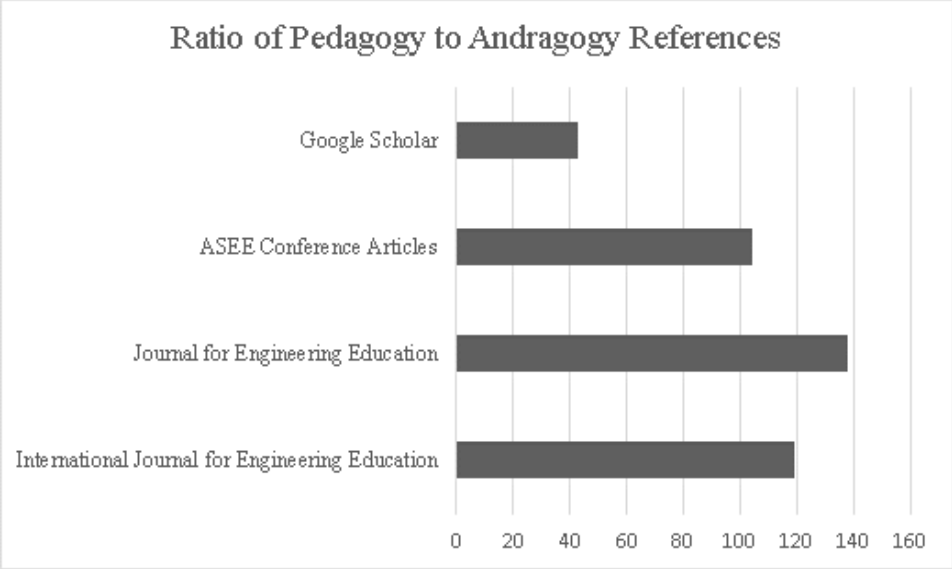

Figure 1: Ratio of Pedagogy to Andragogy References

A further exploration of the engineering education articles that discussed andragogy typically fell into one of two categories. In many cases, the term was used almost interchangeably with the idea of project-based learning (PBL). In project-based learning, students solve problems and work on projects and learn or teach themselves topics in pursuit of solving the problem.[6] Similar to Knowles' idea of activity-oriented learning, PBL is certainly a departure from the more traditional view of the student as completely dependent on the teaching

of the instructor. However, there was little to no discussion in these articles on how PBL fit into any larger view of the student as a more independent, adult learner.

The other category of articles that made mention of andragogy made the connection between the term 'adult' referenced in andragogy, and the idea of adult education. Most of these articles discussed different techniques of how to accommodate adult education students to include differences in marital status, financial obligations, time, and proximity to the place of learning. Again, however, these articles failed to specifically address how to incorporate the principles of andragogy into a comprehensive teaching and learning strategy in engineering curriculum. In this work we take a first step toward the incorporation of andragogical learner assumptions by examining their applicability in one mechanical engineering program.

Methods

Using a single case study methodology, we conducted a comprehensive review of several of the documents that guide not only our engineering program, but also guiding documents of the institution and profession. All of the documents examined in this case study and a brief description are shown in Table 2. The purpose of this examination was to discover mandates within the documents that would favor a teaching and learning approach advocated by andragogy. While the authors recognize that the internal documents are not relevant to an outside audience, it was important to demonstrate how an institution's governing documents could encourage outcomes and objectives more aligned with the concepts of andragogy, without explicitly acknowledging the value of examining andragogy principles.

For the analyses, both authors individually coded each document for language related to any of the five andragogical assumptions. These instances were then evaluated to determine their

degree of alignment with the assumptions. Documents that used language corresponding directly with the andragogical assumption were deemed directly aligned with that assumption.

Table 2: Summary of Documents Reviewed

Document	Description
ABET Criterion 3: Student Outcomes[7]	ABET specified student outcomes (a-k) that prepare graduates to attain the engineering program's educational objectives.
National Academy of Engineering (NAE) report from the Committee on the Engineer of 2020[8]	Multi-phase report on examining the requirements for engineering education in the 21st Century
American Society for Mechanical Engineering (ASME) Vision 2030[9]	Report detailing the current status and long term outlook for mechanical engineering and mechanical engineering technology education.
National Research Council (NRC) How People Learn[10]	Comprehensive research study report summarizing current research in the learning sciences and actual practice in the classroom.
Army Leader Development Strategy[11]	The Army's comprehensive approach to developing leaders for the security challenges of tomorrow.
West Point Leader Development System (WPLDS) Handbook[12]	An institution level document that implements the Army's Leader Development Strategy and defines student outcomes which explain what a graduate must Be, Know, and Do.
Educating Future Army Officer for a Changing World (EFAOCW)[13]	An institution level operational concept for the academic program of the West Point Leader Development System.
Department of Civil and Mechanical Engineering Mission and Vision Statements	Department level statements that communicate the organizations reason for being and explain the organization's future aspirations.

Results and Discussion

Our document review indicated that all five of Merriam's andragogical assumptions were supported by multiple guiding documents (Table 2). In Table 2, cell shading matches the degree of alignment between language in the document and the specified andragogical assumption. Darker shading corresponds to greater alignment.

Table 3: Results of Document Coding

Document	**1 Concept of the Learner**	**2 Role of Learner Experiences**	**3 Readiness to Learn**	**4 Orientation to Learning**	**5 Motivation**
ABET Criterion 3: Student Outcomes					
NAE Engineering Education 2020					
ASME Vision 2030					
NRC How People Learn					
Army Leader Development Strategy					
West Point Leader Development System (WPLDS)					
Educating Future Army Officer for a Changing World (EFAOCW)					
Department of Civil and Mechanical Engineering Mission and Vision Statements					
SCALE					
Directly Applicable					Not applicable

The first governing document the authors reviewed was Criterion 3 from ABET, or student outcomes. These are explicit abilities or attributes that graduates of an ABET accredited engineering program should have upon graduation. Three outcomes that stood out in their connection to andragogy-related concepts are (c), (e), and (i). All three of these ABET Student outcomes showed relationships with category 1 of Merriam's andragogical assumptions as each related specifically to the learner as increasingly self-directed. Outcome (c) also relates closely to category 3, the learner's readiness to learn. Outcome (c) is "an ability to design a system,

component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability."[7] This outcome refers to the student's ability to incorporate design decisions into the context of larger societal and engineering considerations and infers a larger understanding of real-world topics beyond what is taught strictly in engineering coursework. By focusing on the broader requirements and constraints of a design, ABET requires students to consider their work as "real-life" and the need of the student to know and apply their engineering knowledge.

Outcome (e) refers to the student's ability to not only solve, but identify engineering problems.[7] This outcome also supports a mature understanding of the society the student interacts with. A more childlike student may be able to solve engineering problems with proper training and education, but may be less likely to identify that a problem existed in the first place.

Finally, outcome (i) has perhaps the greatest link to the tenets of andragogy when it describes "a recognition of the need for, and an ability to engage in life-long learning."[7] Clearly, a graduate who has achieved outcome (i) has not only the requisite skills to teach him or herself, but has moved beyond goal-oriented learning and toward a learning-oriented approach.

In a comprehensive report on the changes required to ensure the success of engineering education in 2020, the National Academy of Engineering's committee work demonstrated many examples reinforcing principles associated with andragogy. The document makes several references to the increasingly rapid pace of change in the body of knowledge, requiring engineers who are 'lifelong learners'.[7] The report specifically quotes Wright and states that "scientific and engineering knowledge…doubles every 10 years".[14] One particular quote from an appendix in the report states explicitly that engineering educators must "move from the sage on the stage to the guide on the side", further emphasizing the need for students to take a more

active role in their own education.[8] Despite the numerous references in this report to topics that correspond to the pillars of andragogy, the term pedagogy is used 12 times. Andragogy is not used once.

We next examined ASME's Vision 2030 which details the current status and long term outlook for mechanical engineering and mechanical engineering technology education.[9] This document is marked by a series of educational aspirations that expand an engineer's education beyond the traditional scope of technical engineering education to include a broad range of professional skills. ASME also advocates for more authentic or 'practical' educational experiences to better replicate engineering practice. This document applies to all five of Merriam's assumption categories. The broadening of the educational aperture aligns Merriam's description of learner orientation (category 4), the role of learner's experiences (category 2), inspiring a "need to know" (category 3). ASME explicitly states the need for engineering and engineering technologists to, "continually learn and sometimes reinvent themselves"[9] pg. 13 and "develop new knowledge based on a research effort"[9] pg. 32, which is a direct reflection of category 1 and category 5 which describe andragogical learners as increasingly self-directed and self-motivated respectively. These categories describe the need for learning experiences to be organized around competency based categories that will allow learners to live more effectively in the future and acknowledging that knowledge gained through experiences are more meaningful than that which is abstracted from professional practice.

Another important document was the National Research Council's report on learning, titled "How People Learn: Brain, Mind, Experience and School". In the opening section, the report proclaims that "information and knowledge are growing at a far more rapid rate than ever before in the history of humankind"[10] pg. 5, echoing the underlying motivation for andragogy.

The report goes on to classify human learners as "goal-directed agents who actively seek information" and come to "formal education with a range of prior knowledge, skills and beliefs"[10] pg. 10.

Another direct link to the pillars of andragogy is a discussion of the importance of students being involved and eventually taking control of their own learning. In fact, of the three key findings in the report, two correspond to Merriam's first two pillars of andragogy. The report also discusses students' motivation to learn and classifies it as 'intrinsic', also corresponding to a pillar of andragogy. Overall, the report provides a substantial amount of research that would seem to indicate that the principles of andragogy are not only valid for learners, but should be favored for more effective learning. The report uses the term pedagogy 21 times and does not reference the word andragogy once.

The next step the authors took was to examine several documents that comprise key stakeholder guidance both within the institution and in the larger profession the institution serves. While an examination of the particular documents will not be applicable to outside institutions, the exercise is illuminating because it shows how internally, an institution may endorse principles associated without andragogy, without explicitly acknowledging the term, thus potentially misaligning stated goals with behavior.

Because the institution's primary goal is to train officers to serve in the United States Army, the authors examined the Army's Leader Development Strategy. This document describes the rationale behind leader development, the environment in which the training occurs, and the strategy for developing leaders. One excerpt that stood out is how the document describes leader development as a "career-long synthesis of training, education and experiences" and goes on to describe the "self-development domain" where a leader is expected to identify the

need for self-development and achieve that development with little to no outside direction.[11]

Moving down in levels of the hierarchy, a review of West Point internal leader development document, also reveals a realization that leader development requires using learned knowledge and skills to make connections across "experiences, concepts, perspectives, and cultures".[12] The document also specifically addresses the "value of reflection" in the exercise of leadership.[12] Moving further down in guiding principles, West Point publishes a document known as Educating Future Army Officers for a Changing World (EFAOCW) that specifically addresses the role that the academic program plays in the military academy's mission. This document offers some of the strongest evidence of the need for a more prominent role for andragogy. For example, the document states clearly that the military academy "cannot possibly prepare its graduates for the array of scenarios that may confront them throughout their careers"[13] a sentiment directly aligned with an assumption of increasing learner self-direction (category 1) and that echoes the concepts from Knowles on the increasing pace of information creation and social change mentioned previously. There are numerous other instances in the document that describe the need for continued learning and development. The best example of the link in this document to a need for a learning approach that incorporates andragogy is the statement

> With each subsequent year, cadets are increasingly challenged to take greater responsibility for their own learning as the process of cadet education gradually shifts from an emphasis on acquiring knowledge to an emphasis on structuring and using knowledge to deal effectively with challenging new questions, issues, and problems.[13]

Finally, we analyzed the department's Mission and Vision statements shown in Table 4 . The mission statement, was recently revised as a part of a senior faculty strategic offsite. The mission statement's specification of *agile and adaptive leaders* changes the way we view education and acknowledges the need for our students to navigate an evolving operating environment. Navigating this evolving environment will require our graduates to build new knowledge and skills to allow for the agility and adaptation required. This concept aligns with Merriam's notion of increasingly self-directed learners (category 1).

Table 4: Department Mission and Vision Statements

Mission	Vision
Educate, develop, and inspire agile and adaptive leaders of character who design and implement innovative solutions and win in complex environments as trusted Army professionals.	The preeminent developer of undergraduate engineer-leaders and a model learning community of cadets, staff and faculty…

Conclusions

Based on the examination of stakeholder documents and the overall purpose of the institution, it is clear that there is a desire to create graduates with an andragogical mindset. However, at the beginning of an undergraduate experience, students lack some of the attributes that form the underlying assumptions of andragogy. Primarily, students may lack experiences that they can use in their own learning. They may not see the applicability of their learning yet and they may or may not be internally motivated. Thus, the institution must find a way to inspire self-learning by the end of the four-year experience, while recognizing that at the beginning, completely incorporating andragogy into the environment may not be feasible.

The undergraduate experience must incorporate a gradual increase in andragogical concepts and experiences. Pedagogy and andragogy are not a binary choice, but simply two parts of a spectrum of learning experiences.[2] Pembridge studied the concept of a gradual increase in self-

direction in a comparison between first-year and senior capstone design students.[15] He identified statistically significant differences between the two groups in terms of being self-directed and in motivation, both key assumptions required in andragogy.

To achieve the goal of fostering self-directed learning, the institution must be aware of the need to structure learning experiences along the spectrum. Trying to incorporate andragogical practices too early or exclusively in the learning experience could have negative consequences, if the five underlying assumptions are not met. Conversely, failing to incorporate learning practices and experiences based on andragogy at some point in the four-year process will likely fail to produce the desired self-directed learner, so important to the institution's role and mission. The NRC report previously addressed discussed the need for learner-centered environments where the teacher pays "careful attention to the knowledge, skills, attitudes, and beliefs that learners bring to the educational setting"[10] to ensure that the student can fully leverage the experiences they bring to the classroom.

Considerations for Future Work

A review of Knowles' work guides the interested faculty member on practical ways to incorporate andragogical ideas into the learning environment. These techniques range from how the learning environment is physically structured, how learning objectives are prepared, how the student is welcomed and oriented to the classroom, and the very attitude and approach the instructor should have.[2] His work describes a learning environment that is both innovative and 'democratic', a word not typically associated with the teacher-student relationship in academia. Perhaps the most compelling statement is the idea that "education is not concerned with having the instructor perform certain activities; it is concerned with helping students achieve changes in behavior".[2]

The insights gained through this case study lead to a number of considerations for future work. First, faculty may consider taking a critical look at their current teaching and learning assumptions to ensure alignment between their teaching practices and the adult learning requirements their graduates will face. The analyses and resulting conclusions discussed above have informed a revision to the teaching and learning model at West Point's Department of Civil and Mechanical Engineering. A key guiding figure regarding the transition from a pedagogical to andragogical learning environment that informed the revision process is shown in Figure 2. Although the revision process incorporated a number of additional concepts beyond the scope of this paper, Figure 2 became a central theme throughout the process.

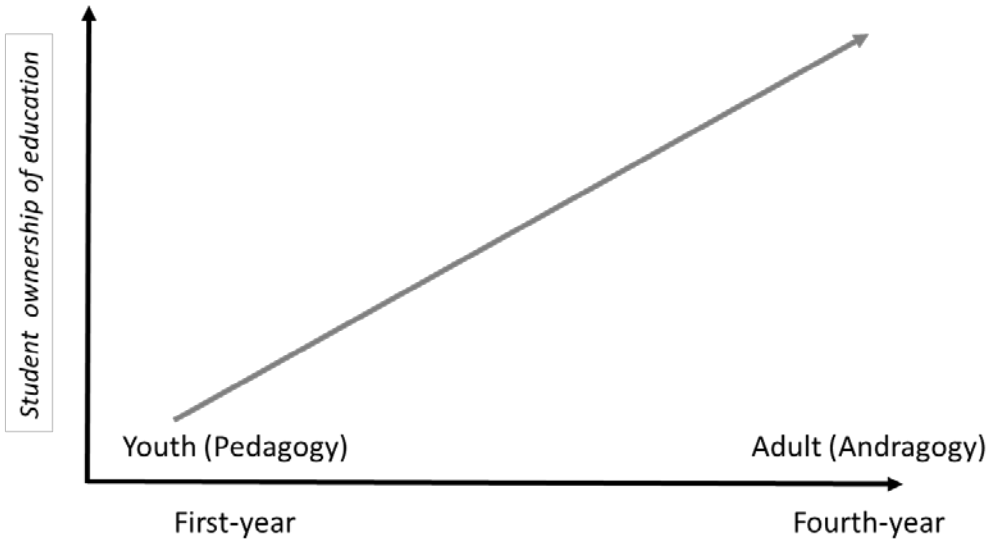

Figure 2: Student transition from youth to adult learning over four-year experience.

Second, faculty may consider how independent study experiences are incorporated into the undergraduate education program. At West Point, there has been a steady increase in the number and scope of independent study projects each year. Currently, nearly 50% of our students complete at least one independent study project for course credit as a part of their four-year experience. These projects provide maximum potential for students to take complete ownership

of learning by proposing and accomplishing their own educational goals in a topic area of interest. In fact, the NRC report states that teachers should not only help students understand the subject matter, but also "help them develop into independent and thoughtful problem solvers"[10].

The results of this study have given the faculty a fresh perspective from which to evaluate the programs and identify additional room for growth. The andragogical perspective has also caused us to cease our well-structured Fundamentals of Engineering (FE) Exam preparation session. Instead, we now focused on a self-directed learning approach to FE Exam preparation stemming from each student's performance on a practice exam. We acknowledge that these learning experiences may be more resource intensive than more traditional courses. Correspondingly, faculty may consider how student generated learning goals may be incorporated into more traditional courses. These self-developed learning goals may assist students in taking greater ownership of their education even in required foundational engineering courses.

Third, faculty may consider having students take an increasingly prominent role in their own education. In early stages of undergraduate education, students can take part in smaller parts of their own instruction in the form of peer teaching and development or short presentations on learning objectives. As the students' progress, this responsibility can be expanded to presenting larger portions of the material, after they have had the opportunity to absorb and review the material with an appropriate mentor. As students move closer to their final goal of completing their studies, they should be called upon to help shape the curriculum or develop their own paths to achieve desired learning objectives. An exercise as simple as developing a recommended syllabus to achieve course objectives would force a student to take on some of the roles of the teacher and less of a pure pedagogical student.

Finally, faculty may consider the structure of homework and design projects throughout the four-year experience. In an effort to harness the assumptions of adult learning, less structured problems that require students to navigate bodies of knowledge to find required information or scope problems may greatly increase their self-directed learning skills. As a department, the work described in this paper have caused us to re-consider how we present problems over the course of the four-year experience and allow students to better develop into adult learners upon graduation.

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