Importance of Foundational Knowledge and Role of Instructors in Academic Calibration

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Abstract: Institutions of higher learning have a responsibility to help undergraduate students gauge their ability to handle course material. Traditional methods that inform students and faculty include establishing course prerequisite(s) in the course catalog and creating barriers to course registration if the designated prerequisite(s) is not met. While the value of establishing prerequisites is not being refuted, this method alone is not always sufficient to ensure students have the requisite foundational knowledge and skills to successfully matriculate through a course. This paper examines the importance of foundational knowledge and skills for engineering students, the use of prerequisite requirements, and surveys practical methods an instructor can use to help students calibrate their understanding of the foundational material once enrolled in a course.

Key Words: prior knowledge, prerequisite courses

1. Introduction

Attrition rates for undergraduate engineering students at universities within the United States remain relatively high. The average graduation rate for undergraduate engineering students sits at 57% (Ohland et al., 2008). Coupled with the increasing need for engineers in the private sector, the high attrition rate continues to cause concern in academic communities, industry, and government. These major stakeholders are motivated to better understand the primary factors that contribute to retention of engineering undergraduate students so that potential interventions can be identified to increase retention rates. Common themes cited in published studies of non-persisting engineering undergraduates can be grouped into the two primary categories: individual and institutional factors (Meyer & Marx, 2014). Individual factors are affect the distinct student experience and include poor academic performance with the curriculum, the feeling of being unprepared for the rigors of undergraduate studies, and the difficulty of fitting into the engineering culture. In contrast, institutional factors affect all students in engineering programs and include student advising and the type of co-curricular opportunities provided to enhance student learning such as student professional engineering society chapters. Retention of students in engineering programs is a multifaceted and complex problem. As factors influencing retention are identified, stakeholders should develop a methodology to mitigate the dominant factors which affect student retention. To that end, this literature review will discuss the impact of poor academic performance in required core engineering courses on retention, will share common institutional practices to prevent poor academic performance, and highlights unresolved issues.
2. The Impact of Student Placement on Retention

Engineering undergraduate programs are traditionally designed so that students will sequentially build the necessary skills and knowledge over the duration of the program (typically 4-5 years). Yoder (2012) found that the level of student preparedness for rigors of a college-level engineering program can influence the student’s subsequent success. Students enter engineering programs with skills gained from previous educational endeavors including high school and possibly community college or college-level classes. As a student progresses through the program milestones, the individual is required to reach a minimum proficiency at the end of each course to continue to matriculate. Sufficient knowledge is often indicated by the earned grade within the course. Students who cannot obtain a minimum proficiency of the foundational material face removal from the program or being identified as “at risk”. These students are likely to face continued struggle within their program and may fail to finish.

Previous research has indicated that success at the start of an engineering program is strongly correlated to persistence in the curriculum. After reviewing longitudinal studies on student retention based on performance in college mathematical courses, Ohland et al. (2004) concluded that students should start college mathematics at a level for which they are prepared. Their finding indicates that assessment of student skills is a critical component of program management. Seymour and Hewitt (1997) found that 40% of science, technology, engineering, and mathematics (STEM) majors complained of inadequate preparation in high school. This finding may indicate that a significant percentage of students enrolled in engineering programs may not have the requisite mathematical skills and therefore be at a greater risk for experiencing academic difficulties. As stated earlier, having a knowledge foundation, consisting of both information and skills, at the start of an engineering course assists students to process the material by ensuring mastery of base skills or providing context for complex ideas.

3. Constructivism, Prior Learning, and Engineering Education

American universities, as aptly described by Frederic Lawrence, exist for the “discovery and dissemination of knowledge for the betterment of our communities and society writ large” (Benson, 2018). To better disseminate knowledge, educators must think critically about what information needs to be shared with students and how best to impart that information. Indeed, over the centuries many articles and books have been published about how to educate others. From that body of knowledge, three main learning theories (behaviorism, cognitivism, and constructivism) that explain the process by which people learn were identified. These three educational theories do not dictate a specific teaching method but rather provide a theoretical foundation on which to build productive methods of instruction or pedagogy. The articles reviewed as part of this literature review utilized constructivism as a basis for their analysis of student success in the classroom. Constructivism states that individuals have a mental model of how the world works and as they gain new information about the world, the mental model is adjusted (Taylor, 2013). Hien (1991) succinctly described the premise for the constructivist model as learners building knowledge for themselves. Jean Piaget, a leading researcher in this field, theorized people process new information either through assimilation or accommodation (Reinking et al., 2000). Assimilation occurs when a student incorporates new information into
what they know but the mental model for the world stays the same. Accommodation occurs when the individual learns new information what changes the structure of their mental model. A key criticism of constructivism is that both accommodation and assimilation are reliant on the individual having an existing base of knowledge for the student to sufficiently process new data. Learning is hampered when students do not possess the identified prerequisite knowledge to connect new information (Mayer, 1975).

Necessary prior knowledge is a critical distinction between desirable difficulties and undesirable difficulties. Desirable difficulties are challenges that are crafted to deepen the learning experience. Brown et al (2014) described a desirable difficulty as something that students can overcome with “increased effort.” As stated in Make it Stick, challenges in learning are valuable only if they “trigger” the encoding and retrieval processes which support comprehension and remembering of the material (Bjork and Bjork, 2011). Undesirable difficulties, on the other hand, are challenges that provide no value to the learning process. This type of difficulty can occur if an individual does not possess either the academic background to deal with challenges (Bjork and Bjork, 2011). The students cannot overcome the challenge because they are not adequately prepared and do not possess required prior knowledge. For example, it would be hard to find a student to complete the second semester of a calculus sequence (Calculus II) without having completed the first semester of this sequence (Calculus I).

Many educational practices are based on the theory of constructivism. For example, the instructional practice of ‘scaffolding’ is dependent on students already possessing a prerequisite information. The technique of scaffolding can be seen when instructors create learning opportunities in which students build knowledge successively. The learning outcome is broken up into discrete skills or concepts. Students are taught to master each discrete part before achieving or accomplishing the overarching learning outcome.

4. The Role of Prerequisites in Student Management

As stated earlier, a key component of constructivism is that students have minimum level of prior knowledge base to successfully learn new information. It is therefore incumbent on an institution of higher learning to develop policies and frameworks that ensure students are enrolled in classes for which they have the necessary prior knowledge. Institutions must examine the desired outcomes for graduates in a program of study and develop a curriculum that helps students reach the stated outcomes. A program should assess what key information or skills students must know at key milestones and determine an optimal progression of learning.

The process of developing prerequisites should consist of developing hypothesis regarding the importance of prior knowledge, gathering data, and the analyzing the data to determine if the student unlikely to succeed in the course unless the student has not met proposed prerequisite or corequisite. For example, Donovan and Wheland (2009) found that the success and retention in undergraduate chemistry increased after the introduction of a mathematics prerequisite. Based on anecdotal evidence from students who had not successfully completed the course suggested that a “lack of mathematics skills had contributed to their poor performance in chemistry”, the team studied the relationship between failure, withdrawal rates and enrolled
student ACT mathematics scores in the fall of 2001. In this case, the implementation of a prerequisite was able to reduce the number of students who failed or withdrew from the course. After a thorough analysis, program management should be able to identify specific pieces of prior knowledge that a student must have to enter each course. An example of specific skills identified for a foundational course is the work completed by Donovan and Wheland (2009). This research team determined that students enrolled in chemistry needed fundamental arithmetic skills or the students would be at risk for failing. In both instances described, the institution was able to pinpoint specific knowledge that students needed to have upon entry to a course to succeed.

The choices that an intuition makes regarding the number of courses with prerequisites, the number of prerequisites per course and the number of course offerings each term can have a significant impact on the student experience and length of the program. As Johnson & Wang (2015) pointed out, striking the right balance between making course requirements sufficient to ensure students can navigate the course material while not too stringent as to limit a student’s ability to enroll in courses offered each semester is difficult. They observed that many programs required that students take courses in a certain prescribed order to ensure that students possess the skills to be successful in the curriculum. However, if the program is too stringent or the student is off cycle the student may have difficulty finding courses that count toward the program graduation requirements. Students may be off-cycle for a variety of reasons to include study abroad programs, internships, medical leave of absence, or having transitioned mid-year from another institution.

A continuing challenge for teachers and curriculum researchers is to determine the best prerequisite course (Choudhury et al., 2007). Most often a curriculum committee will review course listings and determine prerequisites based off material published in course descriptions and on their own experiences taking or teaching a course. The team will determine the necessary prior knowledge needed for a follow-on course, determine which courses teach the prior knowledge, and list all courses as prerequisites for the follow-on course in the academic catalogue. In many cases, the prerequisite listed in an academic course catalogue consists only of the prerequisite course title and does not include the specific information or skills that a student must have to enroll. However, by listing only the course titles, a student is left to determine if their performance within the prerequisite course prepared them for the follow-on course. For example, students who receive a ‘C’ in the earlier course might assume that they have sufficient knowledge to succeed in subsequent courses. However, the student may not have adequately learned a key piece information or skill taught but that key skill was not a significant portion of the material taught in the class.

As noted by Choudhury et al. (2007), some prerequisite courses are more effective than others for preparing students for the follow-on course. For this reason, continued study of the correlation between prerequisites and follow-on courses is advised. As described, establishing prerequisites is an important component of curriculum development. Continual reassessment of the validity of the established prerequisites is warranted since the curriculum continues to evolve. Most universities allow faculty of chance the topical outline and emphasis areas. As the material
in the course evolves over time, the relationship between the established prerequisite and the follow-on course may weaken (Ohland et al., 2004). This is particularly important for departments that use external courses (courses taught in other departments) as prerequisites for a required course.

To enroll in a course, students typically must have either validated or completed the prerequisite course. Institutions have a variety established policies related to validation. To validate courses, students must show the department that the student can already meet the course objectives as outlined in the curriculum guide. Depending on the school, the submission of applicable prior course work, the results of standardized tests such as the Advanced Placement tests, prior transcripts may be used by the faculty to determine if the student should validate. In the case of foundational subjects like Mathematics and English, many institutions have students complete an admissions exam between acceptance and registration. The results of these placement exams help schools place students into appropriately challenging courses.

5. **Why Prerequisites May Fall Short**

In theory, the establishment and adherence to prerequisites should ensure that all students within a classroom have the foundational knowledge to complete a course. Taylor et al. (2017) completed a study at the University of South Florida and found that enforcing requisite requirements for junior level courses decreased student failures within the class 15-18%. However, there are many students who still struggle with course content once they are enrolled. As stated earlier, Seymour and Hewitt (1997) found that 40% of science, technology, engineering, and mathematics (STEM) majors complained of inadequate prep in high school. If these students were placed according to their prior performance (transcripts and standardized test scores), this number indicates that the established prerequisites might not be the best method to screen students. Using assessment tests for placement assumes that all critical skills can be adequately tested within a pre-established time block. Given the wide range of testable material, it is possible that students can perform well on a test, but still have areas of weakness that were not identified in the testing venue. If transcripts are used to assess if a student meets the prerequisites, two issues might come into play. First, if the student took the course at a different institution, the content covered in the prerequisite class might not be the same content or learning objectives covered in a similar course at the accepting intuition. The student could receive an ‘A’ in the prerequisite course and still may not know the foundational material that the accepting intuition felt should be covered in the prerequisite. Content alignment is an acknowledged issue with students who transfer into an undergraduate program. Secondly, the material covered in foundational courses is broad. The student might do well overall in a course, but not have a firm grasp on the material. Since prerequisites typically are listed as the course title and not the specific skill, the student could have passed the course, but not have mastered the required skillset. In addition, grade distributions can vary a great deal within the sections of the same course depending on which instructor taught the section. Karmi and Manteufel (2013) examined the correlation of prerequisite course grades with student performance. The research team found that student grades are highly dependent on the instructor teaching the course. Prerequisites are a means to prevent students for enrolling in a course for which they are not prepared. While
helpful, the measure does not prevent all students from enrolling in courses for which they are not prepared.

6. **The Role of the Instructor in Knowledge Calibration**

In most cases, undergraduate instructors teach large groups of students with a considerable range of abilities, prior experiences and motivations (Croft and Ward, 2001). The diversity of student ability can make developing an instructional plan daunting. The establishment of prerequisites ensures most students have at least a partial knowledge foundation. Once students are enrolled in a course, instructors have the capability to provide students with a last warning about foundational knowledge requirements. Students who continue to remain enrolled in a course without the requisite knowledge will have a greater difficulty succeeding in the course than their peers who have the requisite knowledge.

At the start of the course, an instructor can help students calibrate their academic knowledge by providing opportunities for students to test their mastery prerequisite material. Based on the results of tests, the student can then choose to remain in the course, seek additional support to learn the material, or choose to drop the course without penalty and to potential even register for another course in which the student has a better chance of success. Instructors typically do not have the option to reteach their students the prerequisite material because the course has a finite number of course hours and predetermined course objectives. Publishing requirements for a course and learning objectives ensures that an instructor has a known start point and can focus on the new material.

Developing a curriculum based on constructivist theory presents the instructor with the challenge of determining how much to assume about a student’s ability to organize knowledge when they are presented with new material. There are numerous techniques practiced by a variety of educators while help the instructor determine the academic preparedness of a class as a whole and help the individual student calibrate her level of preparedness.

7. **Instructor Techniques to Assess Prior Knowledge of Students**

Assessment of student mastery of prior knowledge can provide instructors with valuable data with which to inform their program of instruction and to provide individualized student advisement (Dochy, 1992). The following section outlines techniques that have been employed by practitioners within the undergraduate classroom. A short discussion of how to implement the prior knowledge assessment within an academic classroom at the United States Military Academy follows each summary with the aim of sharing best practices with faculty.

a. **Provide an Outline of Specific, Prerequisite Skills:**

Taylor et al. (2017) found that developing an explicit pre-class review of the information required for the course and in-class reinforcement of the information improved student outcomes. For the chemistry course, the instructor provided an outline of prerequisite concepts necessary for understanding. Similarly, Felder and Brent (2016) recommend writing learning objectives instead of just identifying concepts. This outline could assist students in understanding what they need to be able to accomplish.
Providing an outline of specific prerequisite skills is something that can be accomplished at the start of the term. The academic catalogue lists all prerequisites and co-requisites required for each course along with a course description. Using the previously archived instructional memorandums for prerequisite courses, an instructor can review the published lesson objectives. Performing a review of prerequisite course lesson objectives provides the instructor an opportunity to assess if the stated prerequisite is still necessary.

b. Incorporate a Skills Review Test that Students Must Pass

Another method of motivating students to master the prerequisite skills is to require students to pass an initial review exam (Felder and Brent, 2016). Larkin & Bracket (1974) proposed the inclusion of a math review unit followed by a skills test at the start of the term. Before implementing the test, the instructors observed that students enrolled in the introductory physics class at the University of California, Berkley, struggled with basic mathematical skills. At the start of the course, all students took a fundamental of mathematics exam. The test was meant to help students to gauge their competency of basic mathematical skills to include arithmetic, use of scientific notation, geometry, and algebra. On average, only half of the students could correctly answer 80% of the questions. A lack of mathematic skill continued to disadvantage select students the course progressed. The research team noted less than half of students who scored less than 60% on the prerequisite mathematical skills review had a passing grade in the course following the first exam. The next year, the instructional team implemented a mandatory mathematical test. The students are given a list of mathematical skills and must pass the fundamentals test during the first week of class to remain enrolled. The additional requirement forced students to either learn the prerequisite material or leave the course. While giving students an exam can help students identify their deficiencies, instructors must carefully consider what material to test. A key finding from Hailikari et al. (2007) was that the type of prior knowledge influenced student success in the course. Students with procedural prior knowledge performed better in the course than students who only possessed only declarative prior knowledge. Declarative knowledge describes static facts whereas procedural knowledge describes how to perform a skill. Therefore, creating a skills test that is primarily focused on procedural knowledge will provide the student with a better data point for which to assess course readiness.

Creating an exam which tests procedural knowledge and grading the results can be a significant undertaking. In comparison to testing declarative knowledge, procedural knowledge requires students to perform multiple steps to find the answer. To reduce the burden on the instructor, it is recommended to create an exam in an online platform that automatically grades the effort. The use of blackboard to grade tests and provide immediate results on a prior knowledge exam would reduce the workload. An additional benefit would be to create a question repository that randomly selects questions for students to answer. With the permission of the course director of the prerequisite class, instructors can use a prior year’s exam as a prior knowledge test. Depending on the subject, another method to creating an exam is to use a version
of the appropriate Advanced Placement exam for the prerequisite course. The exams are written to fully test a student’s mastery of the subject.

c. Provide Pre-lectures on Prerequisite Material

Depending on the amount of prerequisite material needed for a course, an option to support students without sufficient prior knowledge is to develop pre-lectures. Da Silve and Hunter (2009) discovered that providing first year biology students at Flinders University with pre-lectures reduced the failure rate of students with no prior biology knowledge by half. Prior to implementation, students with no biology background failed at twice the rate of students with the background. The university developed a policy of no prerequisites for first year biology students to increase interest in the program. The change created a financial savings for students who could complete their program in less time. The pre-lecture series consisted of one extra lecture a week that focused on teaching prior-knowledge gaps and prepared students for the material to be taught later in the week. This idea could be modified by creating a repository of online lectures to cover lectures on prerequisite material. In comparison to creating a list of learning objectives and grading a review exam, the creation of videos is much more time consuming. However, this method for helping students overcome prior knowledge deficiencies has the potential to help a wide cross section of students. As pointed out by da Silve and Hunter (2009) review videos have the potential to help all students in a course review material. Strong students observed the videos to help solidify prerequisite skills. At the United States Military Academy, students must graduate within a four year program of study. Implementing too many prerequisites on science courses can complicate curriculum development and force students to transition to other majors. Providing additional instruction which a student can access routinely may be the best approach to make engineering programs available to a greater proportion of students.

d. Encourage Use of Publicly Available Web-based Learning

Adaptive e-learning systems created a personalized approach to learning material. Free, web-based programs are a means of having students conduct self-assessment exams and verify understanding of prerequisite material. Learning platforms such as CodeAcademy, Kahn Academy, and Coursera allow students to progress through material at an independent pace. If the material taught on the online platform overlaps with the prerequisite learning objectives, the use of web-based programs can support students who are attempting to improve their knowledge foundation.

8. Conclusion

The use of prerequisites to ensure that students entering a course have a sufficiently strong knowledge foundation to succeed in the course is a partial solution. Depending on how prerequisites are checked by an institution’s registrar during registration, students may still not have the specific declarative or procedural knowledge desired at the start of the course. As a safety measure, it is incumbent on instructors to help students perform a self assessment at the start of a course. Students need support in calibrating their academic readiness. Based on the
results of the assessment, the instructor can counsel the student to disenroll in the course or help the student catch up on specific skills needed to successfully pass the course.
References


