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Addressing First-Year Interest in Engineering via a Makerspace-Based Introduction to Engineering Course

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Abstract

This Complete Evidence-based Practice article is primarily focused on the impact an introductory engineering makerspace course had on enrolled first-year student's interest in engineering. National retention rates for engineering undergraduate degrees continue to be well below expectations. A major contributing factor is the nature of many first- and second-year gateway courses resulting in an undesirably large number of students leaving the program. If student experiences can be implemented in the first year that augments their interest in engineering such that it offsets the discouragement resulting from certain early course experiences, then students will be more likely to persist through degree in engineering.

Contemporary research has shown that there are individual constructs that not only play an influential role in retention but are even more meaningful than the question of aptitude and/or work ethic. Thus, if these factors can be effectively accounted for, then retention rates can be improved without lowering academic standards. One barrier in particular, often referred to in literature as interest (in engineering), has been the focus of pedagogy for a makerspace-based, introductory engineering course (ENGR 111) that all first-year engineering students at the J.B. Speed School of Engineering (SSoE) at the University of Louisville must take.

The interest barrier, defined in this paper as "student beliefs related to the significance and/or usefulness of engineering", inherently includes student perception(s) related to the level of pleasure experienced in conducting engineering-related tasks or activities. Research has identified interest as the most significant retention impediment for SSoE students; specifically, an increase in interest predicted which students remained in engineering. Yet the significance of the interest question extends well beyond SSoE to engineering programs all over the country.

First-year engineering makerspace courses can have a positive impact on first-year interest in engineering. Not only do makerspaces offer chances for young students to engage in engineering endeavors in creative ways, but makerspaces have shown great potential in addressing broader goals of education, such as the augmentation of first-year engineering student retention. Much of the research on makerspace impacts and practices have focused on K-12 and informal education. Little is known about how a well-designed, makerspace-based engineering course can address barriers to first-year students' persistence in engineering, such as the interest in engineering barrier focused on in this paper.

Research also suggest that the makerspace movement provides a beneficial opportunity for student development of interests and identity. The structure of ENGR 111 provides a context and potential for addressing motivational barriers, such as interest in engineering, in a manner that traditional classrooms cannot do. Likewise, ENGR 111 provides students the situational means to experience problem solving in a way that wouldn't be possible in a traditional course structure. While research in college retention has focused on integration into the university, research in *engineering* retention has focused more on integration into the engineering culture; thereby making ENGR 111 an ideal mechanism for addressing the first-year interest barrier. This

study employed a post measure of students, asking about their individual interest in engineering and how impactful their ENGR 111 course experience was on their response to the interest query. This paper reports on the results and outcomes.

1. Introduction

Typically, national retention rates in Science, Technology, Engineering, and Mathematics (STEM) hover around 50% [1]. A major contributing factor to this fact is the nature of many first- and second-year gateway courses (e.g. course is very difficult, course appears unrelated to student choice of major), resulting in an undesirably large number of students that drop out or fail [1]. This is certainly true at the J.B. Speed School of Engineering (SSoE) at the University of Louisville, where engineering-based mathematics courses are taught "in house" during the first two years of undergraduate programs. Multiple studies [e.g. 2] have shown that the challenges faced within this math sequence are driving factors in SSoE student attrition. The authors posit that, if student experiences can be employed in the first year that outweigh the discouragement resulting from experiences in certain early courses (such as the math sequence), then students will be more likely to persevere through these courses and thusly continue in engineering.

An exciting prospect in effectively serving the aforementioned need is a course based in makerspace pedagogy. While makerspaces have excited considerable interest, much of the research on makerspace impacts and practices have focused on K-12 and informal education. Little is known about how a well-designed makerspace-based engineering course can address barriers to first-year students' persistence in engineering. SSoE does indeed offer an analogous student experience in a course titled *Engineering Methods, Tools, and Practice II* (ENGR 111) [3-5]. ENGR 111 is a relatively new course that centers around a suite of hands-on, makerspace-based activities. In addition to the primary course objective of teaching fundamental engineering skills to first-year SSoE students, ENGR 111 is designed to build students' interest in engineering, and their perception of themselves as someone who can be an engineer. Furthermore, the makerspace platform fosters ENGR 111 curriculum exclusively based in active learning, which would further efforts in improving retention. Studies have shown that an active learning environment produces strong indications of success and increased retention rates in engineering [6-8].

2. First-Year Engineering Retention

2.1 Challenge(s) of First-Year Engineering Retention

Market demand for engineers continues to be quite high, as engineers remain amongst employer listings of the toughest jobs to fill [9]. One obvious means that would significantly boost the engineering workforce, throughout both industry and academia, would be to improve student persistence (i.e. retention) within engineering programs [10]. Nevertheless despite demands to increase the totals of STEM graduates [e.g. 11-14], there has been an alarming decrease over the past several decades in the number of students persisting in procuring engineering degrees [15-16]. Concurrently, there are mounting pressures from local and national governmental concerns related to student debt and retention, and from collegiate leadership due to the use of retention and graduation rates in institutional rankings [17]. Accordingly, one of the most currently studied topics in higher education is student retention [18].

Increasing the number of graduating engineers is difficult because factors associated with engineering student retention are multidimensional and not fully understood [19-20]. Numerous reports verify that an increase in first-year engineering student retention increases the number of engineering students earning undergraduate degrees, yet the first year of engineering undergraduate education presents several hurdles for students [21]. At first glance, one may assume that factors such as student aptitude (understanding engineering concepts) and work ethic (study and preparation skills) are the leading contributors to student attrition. However, the vast majority of engineering students, whether they are aware of it or not, do certainly have the required aptitude to succeed (apparent in the fact that they met the engineering school admission criteria), and work ethic is a characteristic that all can attain (if they do not already have it). While these potential barriers of aptitude and work ethic surely play a role in effecting retention, modern research has shown that there are other individual constructs that not only play a very influential role in retention, but are even more meaningful than the question of aptitude and/or work ethic. Thus if these factors can be effectively accounted for, then retention rates can be improved without lowering academic standards.

According to Matusovich et al. [22], remarkably little research has been performed from the student perspective, with even fewer research explaining how student persistence occurs. Matusovich notes a large-scale study by Seymour and Hewitt [23] focused on student retention in science, math, and engineering fields. Results of this research showed that choices to leave respective fields were usually not due to poor aptitude or work ethic, but instead were more related to diminished perspectives on the reason(s) they chose that field in the first place. Based on these results, the premise is that motivation fueled by interest is a key factor in students' persistence in engineering.

The types of factors that contribute to student attrition (which will be nomenclated in this paper as "barriers") can be traced back to the work of J.S. Eccles, considered to be a pioneer in the expectancy-value theory of motivation [24-26]. Eccles' theory, in its simplest form, states that decisions to continue in activities, such as earning an engineering degree, are formed by beliefs in competency and value. Competency beliefs are defined as individual expectations of success and encompass one's belief as to how well he or she will perform in a given activity [24], and they have been linked to improved task performance among collegiate students [27]. The principles of the competency-belief component of this theory are similar to Shavelson's self-concept of ability [28] and Bandura's self-efficacy construct [29]. While by definition, these three concepts are different, they have proven difficult to isolate empirically [30-34] and are usually measured in the same manner [27]. Competency beliefs are frequently grounded in self-efficacy theory [22], which facilitates the connection between positive feedback and better academic achievement [35]. Value beliefs, on the other hand, have been studied less often but are by no means less vital. While competency beliefs focus on a person's *ability* to do a task or engage in an activity, value beliefs focus on an individual's *desire* to engage in an activity or task. In addition to the impact they have on student retention, research directed towards understanding value beliefs show that they predict undergraduates' intentions to attend graduate school [36]. A key retention barrier associated with value beliefs is interest value, which intuitively tracks since interest is strongly linked to an individual's desire.

2.2 The Interest in Engineering Barrier to First-Year Engineering Retention

As stated earlier, countless researchers have reported strong correlations between retention and motivation, and, amongst the literature, many barriers impacting first-year engineering student retention have been identified and reported on. It is not practical to provide universally agreed-upon definitions for the entirety of barrier terminology since various authors in the field have interpreted some terms differently.

The interest (in engineering) barrier is the focus of this paper and is generically defined as "student beliefs related to the significance and/or usefulness of engineering." This definition inherently includes student perception(s) related to the level of pleasure experienced in conducting engineering-related activities or tasks, and/or the level of pride associated with becoming a professional engineer. Interest has been identified as the most substantial barrier because research has shown this to be the case for SSoE students. In the one study [37], it is stated that change in interest is a critical predictor of SSoE first-year retention; specifically, an increase in interest predicted which students remained in engineering. In a 2011 study conducted with SSoE students [38], students from a freshman cohort were instructed to respond to nine different factors (i.e. potential barriers) and rank the top three they considered when deciding on what career to pursue. The interest factor/barrier was selected as #1 by the highest percentage of students and was present in the top three for the highest percentage of students. Another SSoE study in 2016 [39], was exclusively focused on the effects interest in engineering had on first-year retention. Out of the top three factors/barriers students picked to study engineering (interest in engineering, job availability, and good pay), interest in engineering was the *only* barrier specified as reason to *leave* the school of engineering. The same investigation included a supplementary study on retention as it related to interest. First-year SSoE students were categorically grouped to inform a 2x2 matrix analysis (Figure 1): first-year students with below versus above average GPA, and first-year students with low versus high engineering interest. For above average GPA students, there was a 27% increase in retention for those with high interest (versus low interest), while there was a 40% increase in retention for below average GPA students that possessed high interest in engineering.

		GPA	
		Below average (Low)	Above average (High)
Interest: Low	Equal or more interested in another field (Low)	STEP-OUTS (n = 38, 11%) Retained 21% Switched units 29% Left university 50%	SEARCHER (n = 36, 10%) Retained 67% Switched units 25% Left university 8%
Interest: High	More interested in engineering than any field (High)	STRUGGLERS (n = 102, 29%) Retained 61% Switched units 15% Left university 24%	STARS (n = 176, 50%) Retained 94% Switched units 3% Left university 2%

Figure 1. Retention framework related to SSoE interest in engineering study by Honken et al. [39].

Although the previous text is pertinent to SSoE students, the significance of the interest barrier extends well beyond to engineering programs nationwide. Various studies show that barriers related to engineering interest, significance, and usefulness are the most likely determinants of engineering students' intentions [10, 24, 40-42]. A highly cited multi-institutional study [43] assessed why engineering students expected to be successful left the school. Loss of interest in engineering was a top identified barrier. In their longitudinal study on engineering retention, Seymour and Hewitt [23] stated level of interest as "salient" to career choices. Also, an investigation at the University of Pittsburgh [44] documented loss of interest of engineering as a major cause for leaving the engineering program.

3. The Makerspace Course: *Engineering Methods, Tools, & Practice II* (ENGR 111)

The ENGR 111 makerspace course is a key mechanism for implementing interest in engineering augmentation for first-year SSoE students. In addition to details related to the existing state and benefits resultant from the active learning nature of the course, the text that follows addresses current makerspace knowledge base, and connects the underlying theory discussed above to the makerspace experience.

In the fall of 2014, SSoE commenced an endeavor to renovate the school's existing course(s) focused on introducing first-year students to the profession and fundamentals of engineering, resulting in a two-course sequence that all first-year SSoE students (no less than 450 per year) are required to take. Motivational factors in the desire to restructure included aspiration(s) to conform to the latest research in engineering education methodologies, the opportunity to uniquely impact the first-year experience via a newly-opened makerspace on the university campus, the provision of a common first-year for all SSoE students, a yearning to boost student potential for success in subsequent courses, and to deliver a more substantial, realistic first-year exposure to the engineering design process. The first component of this sequence, *Engineering Methods, Tools, & Practice I* (ENGR 110), is structurally analogous to the previously-existing introductory course and is primarily focused on introduction to and practice with fundamental engineering skills. The second component, *Engineering Methods, Tools, and Practice II* (ENGR 111), was essentially built from “scratch” and is primarily focused on application and integration of the fundamental skills learned in ENGR 110. Fundamental skills that has been integrated within this course include 3D printing, basic research fundamentals, circuitry, communication, critical thinking, design, engineering ethics, hand tool usage, problem solving, programming, project management, teamwork, and technical writing.

ENGR 111 culminates in team-based Cornerstone projects that all students demonstrate and present at the end of the semester. Throughout the semester up to Cornerstone demonstrations, course instruction, activities, and deliverables have been designed in a dual-purpose manner, in that they augment student practice of essential engineering skills while at the same time scaffolding progression towards Cornerstone Project completion. The Cornerstone Project for current course iteration(s) involves the construction, optimization, and mechanical design of a windmill system; which includes the integration of a windmill, student-built AC motors, DC motors, circuitry, and data acquisition systems. Cornerstone demonstration assessment is divided into two separate components, one dedicated to author-developed design challenges integrated within the windmill system, and the other dedicated to student-programmed windmill parameter display. By means of integrated circuitry and programming executed via Arduinos platform and Programmable Logic Controllers (PLCs) [45], Cornerstone demonstration(s) related to the programming aspect involves the inclusion of an LCD screen that displays five different, real-time windmill system parameters upon toggling of a pushbutton. These displayed parameters are 1) windmill speed (in revolutions per minute), 2) windmill system power output, 3) windmill blade efficiency, 4) windmill motor efficiency, and 5) windmill system efficiency.

A couple of other ENGR 111 features pertinent to this paper include a high level of faculty interaction with students during class time, with a minimum of six personnel (combination of faculty and teaching assistants) manning each class. This is noteworthy as it has been documented that there is a strong correlation between level of faculty interaction and the interest barrier [46]. The course is also heavily team-based, which is significant because, if scaffolded appropriately, putting students into teams adds a level of complexity that enhances the experience [8, 47-48]. ENGR 111 student feedback pertaining to the teamwork experience has been overwhelmingly positive thus far [5].

ENGR 111 also employs various forms of active learning. Prince [49] defines active learning as “any instructional method that engages students in the learning process”, yet active learning is often juxtaposed to the traditional lecture where students inactively receive information from the lecture. Generally, active learning refers to activities that are introduced into the classroom, with the core elements of student activity and engagement in the learning process. In summary, active learning necessitates students to do meaningful learning activities in conjunction with thinking about what they are doing and why [50].

Perhaps the most important feature of ENGR 111, as it relates to this article, is that the course is conducted in a makerspace; more specifically, a 15,000 ft^2 makerspace called the Engineering Garage (EG). In simplest terms, a makerspace is a physical location (the EG) that serves as a meeting space (ENGR 111). More advantageous than simply being a physical space for meeting, many institutions utilize makerspaces as a means to offer training and/or teaching in new skills and/or knowledge [51]. For quite some time now, many colleges have provided makerspace-analogous functionalities, including assembly/testing areas, machine shops, Computer Aided Design laboratories, and/or classrooms. What universities often disregard is the inclusion all of these elements in one location [52]. For campuses that do implement such centralized accommodations, the majority of these makerspaces are utilized predominantly for informal settings. Utilizing a makerspace for housing an introductory course in engineering, such as ENGR 111, fosters a formal setting that includes a variety of disciplines that draws in diverse backgrounds and varying levels of expertise.

If structured properly, certain first-year engineering courses can have a significant positive impact on first-year retention [53]. Makerspaces present an opportunity to transform countless engineering programs by providing an educational means of student engagement via hands-on projects and further development of a large range of fundamental engineering skills that are currently being underdeveloped [54]. A recent extensive makerspace examination [55] regarded them “only in a positive way”, as there were virtually zero negative effects found in the work reviewed. Not only do makerspaces offer opportunities for young people to engage in engineering practices and knowledge in creative ways [56], but makerspaces also posit great potential in serving broader goals of education [57-60], such as the critical goal of enhancing engineering interest; thusly augmenting first-year engineering retention.

Historically, a main reason that students leave engineering is the lack of engineering related experiences in the first year [61]. Conventional first-year engineering curricula require students to complete multiple gateway courses (i.e. basic mathematics and science courses) prior to beginning disciplinary coursework. These courses oftentimes deal with abstract material with little perceived engineering context. As a result, students end up believing that all engineering courses will be similar, and some ultimately leave for other professional arenas where applications can be understood much earlier in academic career(s) [62]. One approach in addressing this issue is to send students out into the workforce early in their academic career(s), providing them the benefits of experiencing direct engineering applications in a real-world context. This strategy is often denoted as cooperative education (co-op). Co-op has been shown to improve both student performance and retention [63-64]. The co-op experience is mandated as part of the degree requirements at SSoE, yet all SSoE co-ops don’t start until *after* the first year. Thus ENGR 111 is an ideal first-year supplement to impending co-op experience(s). Another approach in addressing student disenchantment with first-year engineering coursework has been the augmentation of first-year engineering experiences, either via engineering specific courses or integrated pedagogy, to provide support and context for the requisite gateway courses and to provide more substantial engineering-related experience [62]. Use of these strategies has been shown to improve retention of students in engineering fields [65], and ENGR 111 employs such methodology.

Amongst other attributes, the makerspace movement provides an excellent opportunity for student development of interests (and identity) [59]. Dougherty [66] declares that the term "maker" is universal and essential to human identity, "describing each one of us, no matter how we live our lives or what our goals might be". A common reason students pursue engineering is because they enjoy the process of creation and the ability to work with their hands [53], and such practices are certainly prevalent throughout ENGR 111. The structure of ENGR 111 provides a context and potential for addressing motivational barriers in a manner that traditional classroom testing cannot do. For example, one thing engineering students often fail to learn in the conventional classroom is that "failure" is not something to be feared. With so much focus on achieving the highest possible GPA, the ENGR 111 makerspace environment gives students an outlet to learn that failure is also a part of the learning process (not to mention the Engineering Design Process). It should not be considered an obvious sign that engineering isn't a good fit, thus resulting in leaving the program. Likewise, ENGR 111 provides students a tangible means of visualizing how problems can be solved in a way they would not see on paper, when the critical engineering skill of problem-solving can get lost amid memorization and anxiety. While research in college retention has focused on integration into the university, research in *engineering* retention has focused more on integration into the engineering culture [22]; thereby making ENGR 111 an ideal mechanism for addressing first-year engineering retention barriers.

4.0 Preliminary ENGR 111 Results (with Respect to Interest in Engineering)

In the Spring 2019 iteration of ENGR 111, students were surveyed on their current interest in engineering. The first related question tasked students with choosing one of five different categorical options pertaining to interest level. Each of these levels, procured via validated survey data from the GEARS database [67], were specified as 1) only interest ("I am so interested in engineering that I cannot imagine myself studying anything else"), 2) high interest ("I am very interested in engineering, but also think I could be happy in another field"), 3) equal interest ("I am equally interested in engineering and equally interested in another field(s)"), 4) low interest ("I have an interest in engineering but stronger interest in another field(s)"), and 5) no interest ("I'm not interested in engineering; I chose engineering for reasons other than interest"). Students were then instructed to answer a follow-up question that asked the degree of impact their ENGR 111 experience had on their answer to the previous question related to interest – specified as "significant impact", "somewhat of an impact", and "no impact". The results are shown in Figure 2.

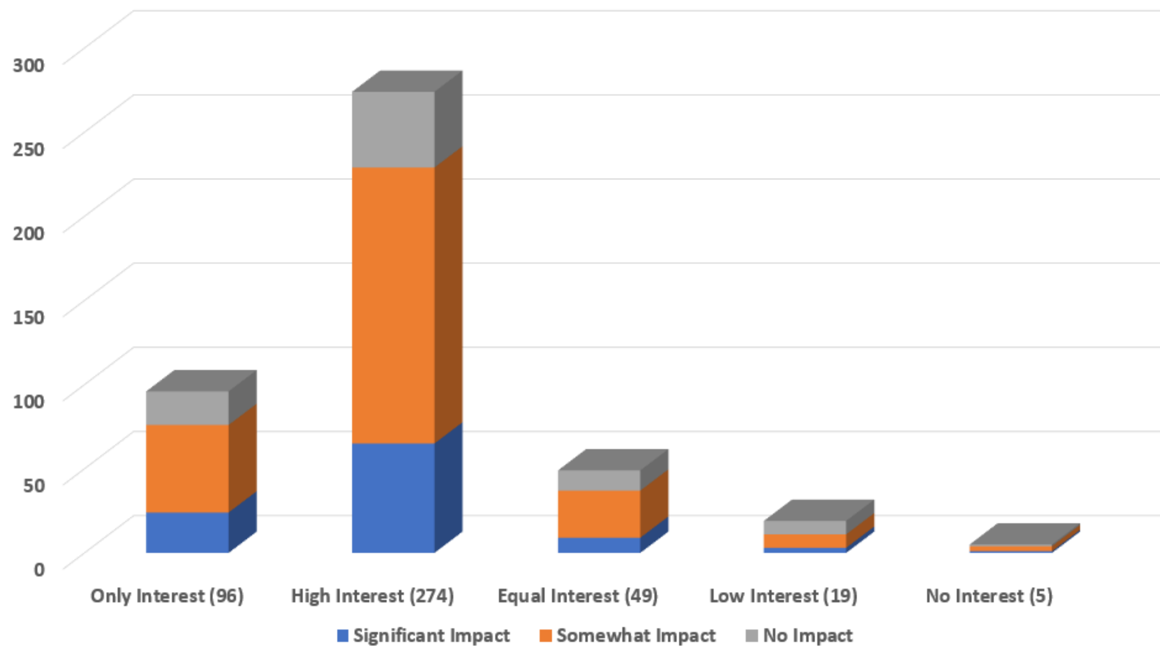

Figure 2. Results for Spring 2019 ENGR 111 student responses to interest barrier.

The results shown in Figure 2 demonstrate the ENGR 111 potential to positively impact retention barriers. Out of the 443 total students surveyed, 79.17% of the 96 students that specified engineering as their only interest stated that ENGR 111 had at least somewhat of an impact (one out of every four expressed *significant* impact). Furthermore, 83.57% of the 274 students that specified high interest in engineering credited the course with at least somewhat of an impact (with 23.72% expressing significant impact). A mere total of five students expressed no interest in engineering, and the combined percentage of surveyed students that selected equal, low, or no interest was 16.48%.

5.0 Future Work

Utilizing the Linnenbrink-Garcia et al. study [68] as guidance, additional efforts are ongoing to further assess the link between first-year student interest in engineering, the ENGR 111 makerspace experience, and first-year retention. The aforementioned study highlights research that suggests student interest can be conceptualized into two main types of interest: individual interest versus situational interest. Individual interest has a dispositional quality and is specific to the individual across continuing experiences. Situational interest, on the other hand, emerges as a result of specific environmental experiences (such as ENGR 111). Theoretical models of individual interest identify instances of situational interest as vital in the development of individual interest, and individual interest has been identified as the best measure for persistence throughout academic careers (i.e. beyond the first year) on to earning degree(s) in engineering.

In addition to the queries specified in section 4.0, pre and post measures that surveyed students on questions aligned with individual interest were also administered to ENGR 111 students in the Spring 2019 semester. Another study [69], used to inform the Linnenbrink-Garcia et al. work, categorizes three different characteristics ("interesting", "useful", and "important") that frame individual interest. Results from these surveys are currently being assessed to study the measure(s), via sub-factor analysis for the three previously-mentioned characteristics, applicable to first-year engineering students. Furthermore, course administrators are also in the process of developing measures related to situational interest, which is more applicable to the ENGR 111 experience, with the objective of studying how situational interest evolves into lasting situational interest. A related journal article is forthcoming.

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