Building a Successful Fundamentals of Engineering for Honors Program

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Abstract

In the early 1990s, Ohio State found that all incoming engineering students were being retained to graduation with a degree in engineering at a rate of about 38 percent. Honors students were being retained at approximately a 50 to 60 percent rate. In 1992, Ohio State joined with nine other engineering colleges to form the Gateway Engineering Education Coalition where one of the goals was to improve retention. Other goals were to develop modern curricula, to introduce technology into the classroom, to develop faculty to be better teachers, and to develop students to be better and life-long learners. The model for developing Ohio State's lower division programs was Drexel University's E4 program. This paper describes the development of the Fundamentals of Engineering for Honors Program at Ohio State, the resulting increase in retention, the building of community, the effect on recruiting good students, and the support of industry.

1. Introduction

Over the past ten years, learning experiences for first year engineering students at Ohio State have evolved notably in a number of ways. Some of earliest of this evolutionary progress was partially documented[1-4] in previous efforts. The present work provides both comprehensive and up-to-date description and details of the Fundamentals of Engineering for Honors Program (FEH), in part by incorporating some highlights found in more recent companion papers[5-8] into one work.

In response to a national concern in the early 1990s about poor retention of students in engineering combined with a real, or some would say critical, need for more engineers, Ohio State worked with nine other schools to form the Gateway Engineering Education Coalition. This need for engineers was and currently is driven by society's ever-increasing consumption of technology. The Coalition, led by Drexel University, was established as a result of the creation of an Engineering Education Coalitions program by the National Science Foundation. The Gateway schools agreed to adopt or adapt Drexel's E4 program[9-12] for freshmen and sophomores which put engineering "up-front" and specifically included hands-on labs and incorporated design projects. Introducing design in the freshman year[13-17] of engineering course work was a mark of change for a number of engineering programs in the last decade.

Putting engineering up front and incorporating the hands-on laboratory experiences was intended to attack the problems of poor retention by getting students involved and excited about engineering right from the beginning of their first term. An important element here was (and is) the use of regular faculty from across the departments of the College in the first-year courses to provide significantly more interaction between first-year student and engineering faculty, which establishes a sense of identity with or belonging to engineering. It provided and continues to offer the additional benefits of advancing toward the goals of increasing diversity, developing a dynamic curriculum able to respond and adapt to the changing needs of the engineering workforce, and using technology.

One might be tempted to remark that incorporating design in the freshman year is mostly just a very logical extension of engineering up front. Certainly on the whole this may be true. But at Ohio State the results of a College of Engineering survey in 1992 of 20% of the most recent five year graduates[18-19] revealed a strong reason to introduce team-oriented design/build projects. The survey of the graduates (and also of their employers) gathered information about both the importance of and their preparation in skills grouped in four broad areas: a) basic engineering skills, b) basic graphics skills, c) computer skills, and d) communication and problem solving skills. Without exception, the graduates from the years 1987 to 1991 and their employers indicated that the level of preparation was noticeably below the level of importance for writing skills, oral communication skills, problem solving skills, and teamwork. Clearly, design/build projects completed by small teams of students and incorporating written reporting assignments, oral presentation requirements, and graphical documentation could help address the preparation shortfalls revealed by the survey. With engineering up front, it was logical to put some of these design projects into the freshman programs in addition to such projects traditionally positioned in the junior and senior years of the curriculum.

2. The Early Efforts

For several years, the Ohio State engineering faculty and academic advisers had observed that many students dropped out of engineering before completing the pre-major core curriculum. Stark reality was brought home somewhat later by a careful study[20] of 1988 first year engineering students that was completed in 1996. This study revealed the overall retention rate for freshman students who expressed an intention to study engineering was less than 40%, with most attrition occurring during the first and second years. Against this backdrop of poor retention of engineering students and preparation shortfalls in those that did graduate, a small group of Engineering Graphics, Industrial Engineering, Electrical Engineering, and Engineering Mechanics faculty worked together with a few select, cooperative faculty from the Mathematics and Physics departments to create an adaptation of Drexel's E4. The E4 program combined Chemistry with Biology and Math with Physics. Engineering had both a lecture portion and a hands-on lab portion. Humanities were taught with communication, and there were both technical and non-technical components. Drexel's retention results and feedback from industrial co-op employers were both very positive. The retention in engineering was well above 60 percent.

The "Gateway" pilot program, as Ohio State's adaptation was then called, originally consisted of a set of courses that included: a combined mathematics and mechanics sequence covering four calculus courses, statics, particle dynamics, and rigid body dynamics; and also a fundamentals of engineering lecture and hands-on lab sequence. The faculty coordinated the math, physics, and engineering course material so that topics were delivered before being used in a companion course. The "Gateway" pilot was first offered in the 1993-94 school year to new first quarter freshmen who had calculus in high school and who placed into advanced calculus by the University's math placement test. Key components of the program were the material from engineering graphics (EG) courses, EG 166 and EG 167. The former was a traditional introductory engineering graphics course and the latter a beginning computer programming course with emphasis on engineering problem solving. Both of these courses were heavily augmented with a series of weekly hands-on laboratories, and a new EG course consisting of a quarter-long team design/build/test/document project was added to complete the three course sequence. Longitudinal tracking showed that 85 to 90% of the students in the first pilot were being retained compared to 70% retention for a matched control group of accelerated math students taking the standard EG 166 - EG 167 sequence which had no physics and math coordination and no hands-on laboratory experiments.

Over the course of the first few Gateway pilots, both the course content and range of offerings were varied to determine which of several approaches might prove most effective in meeting the goals outlined by the Gateway Coalition. By 1996 the course content and offerings had optimally stabilized to the point where it was proposed to the College to approve "Gateway" for all students. The proposal was approved "for honors students only" beginning with the 1997-98 school year, and the program became the Freshman Engineering Honors (FEH) Program. Since 1997-98 the FEH Program has grown in demand by honors students from about one-fifth of those eligible in 1997 (or about 70 students) to three-quarters of those eligible in 2003 (or approximately 280 students). The growth in honors student enrollment in the first-year engineering honors program is shown in Figure 1 below. It has undergone one more name change to the Fundamentals of Engineering for Honors (FEH) Program, retaining the "FEH" nickname which had earned some recognition from among a number of the top companies that recruit and hire Ohio State Engineering graduates.

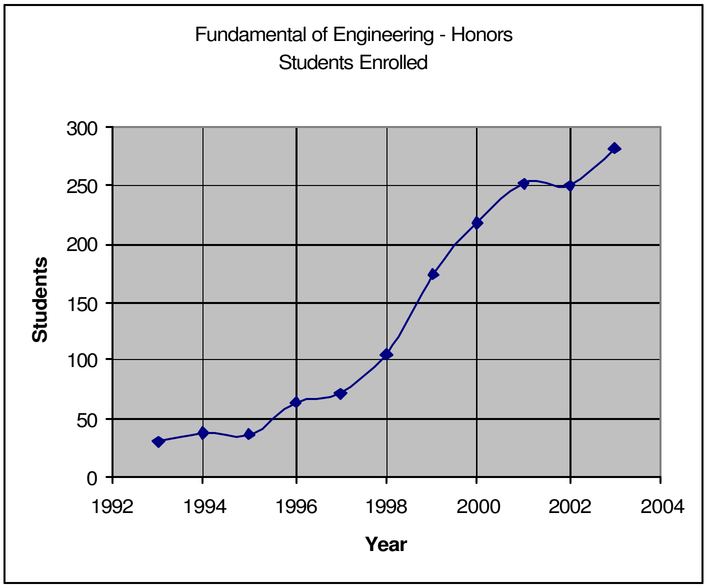

Figure 1. Growth of Student Enrollment in the Fundamentals of Engineering for Honors (FEH) Program from 1993 to 2003.

3. The Present Configuration

Engineering - The present curriculum for the first year is shown in the Table 1 below. The Engineering topics covered include engineering graphics, CAD, C/C++ and MATLAB programming. There are hands-on laboratory exercises scheduled for all three courses. There are two-person and four-person design/build projects varying in length from four days in H191 and six days in H192, to a full quarter in H193[21]. For the past ten years, most of the student teams designed and built small autonomous robots. In the spring of 2003, the FEH robot competition attracted 900 to 1000 spectators. Within the Engineering courses, the faculty use active learning in the classroom. Collaborative work is expected in the team-based hands-on laboratory experiences and the design/build projects.

Physics – The Physics 131I, 132I, and 133I courses are coordinated with the Mathematics instruction and the Engineering instruction. Under the leadership of Alan Van Heuvelen the sections for the FEH students incorporated active learning in large (~72 students) sections and collaborative learning in the recitations and laboratory exercises (~24 students).[22-23] The laboratory exercises are set up for experiential learning. The students are organized into Learning Teams for the collaborative work including taking 12 percent of their midterm exams as a team. This part of their examinations consists of a complex problem that the team must break into parts, solve the parts, and then assemble the partial solutions to solve the problem posed. On nationally normed exams these students have produced test results that are among the top in the USA.

Table 1. Schedule of Courses for the First-Year Engineering Honors Student

First-Year Engineering Honors Schedule					
Autumn Quarter		Winter Quarter		Spring Quarter	
Course Name	Cr Hrs	Course Name	Cr Hrs	Course	Cr Hrs
Engineering H191	4	Engineering H192	4	Engineering H193	4
Math 161G or Math 151A	5	Math 162G or Math 152A	5	Math 263G or Math 153A	5
Physics 131I	5	Physics 132I	5	Physics 133I or Mech Eng H210	5 or 4
Engineering 100	1	[English 110]	[5]		
Total Credits	15		19		14/13

Mathematics – Two different math sequences (Math 161G, 162G, 263G and Math 151A, 152A, 153A) are part of the FEH program. A majority of the students have taken calculus in high school and take an accelerated sequence (16xG) that covers four quarters of calculus in three quarters. Some are much further ahead in their mathematics preparation and begin with a higher level, non-FEH math course. Most of the rest of the students take an applied calculus course sequence (15xA) that uses the Harvard Calculus book. In both FEH math sequences, the students have study teams. Students who may be farther ahead in their calculus sequence my still participate in the FEH Program.

Mechanical Engineering – In the Spring quarter, students have the option of taking a Mechanical Engineering course (Mech. Eng. H210) that covers statics instead of the third course in the physics sequence, Physics 133I. In this statics course students are placed in study groups for solving the assigned homework problem sets.

4. Key Features of the Engineering Design/Build Project

In Engineering H193 the students are formed into teams and then given the scenario for the robot competition. They learn about team formation and teamwork, project planning, management and documentation. One of the teams' first tasks is to develop a team working agreement that specifies the expectations for each member, how decisions will be made, and what happens if a team member does not do her/his share of the work. The second task is to look at when the competition is held and develop a plan to complete the tasks with start dates, end dates, and due dates. The Engineering faculty have weekly meetings with the student teams and review the team's progress and compare it against the schedule that the team developed. The faculty also review the project notebook that each team keeps.

The teams are required to submit a progress report about one third of the way through the quarter. The teams also have to draft the first half and later the second half of their final written report. They have to prepare an outline for their oral presentation. After the robot competition that normally occurs in the ninth week of the ten-week quarter, the teams have to make their oral presentation and turn in their final reports, their project notebooks, and a copy of the slides that they used for their oral report. Their final written report has both a solid model of their assembled robot and dimensioned drawings of the parts.

A picture of the 2002 FEH Robot Competition is shown in Figure 2. The autonomous robots had to pick apples from trees located through a multi-level orchard and deposit the apples in a designated collection bin. Apples were to be picked from at least two different varieties of trees.

Figure 2. The 2002 FEH Robot Final Competition.

In addition to the design/build/document project experience, FEH students can read and create sketches and CAD drawings, write computer programs in C/C++ and MATLAB, and go into a lab and take and analyze experimental data.

When the students interview with companies as they seek co-op or internship appointments, they are encouraged to take their final report and project notebook to the interview so that they can discuss what they have accomplished in a team project. Most interviewers are impressed that a first year student has had such a rich experience and many of the FEH students work in industry after their first year.

5. Classrooms and Laboratory Rooms

The classroom and laboratory spaces that were used by the Gateway pilot program for the first few years were designed for entirely different instructional purposes. When the FEH program was permanently approved and a companion program for non-Honors students had been approved for piloting, the College found and renovated laboratory space. This was used for a year on an interim basis while planning was done for the classrooms and laboratories to properly house the First-Year Engineering Program.

Each course in the FEH sequence has two components: basic skills and laboratory exercises. In the basic skills portion of the class, students study engineering graphics through sketching, visualization, and CAD. They also learn oral, written, and graphics communications skills; how to use of computer software for word processing, spreadsheets, mathematical calculations through C/C++ and MATLAB; and how to prepare visual aids. In the laboratory portion of the classes, they design and conduct experiments to investigate fundamental concepts, take apart off-the-shelf products to explore the engineering design process, and then design, build, test and document a product of their own.

The basics and laboratory portions of the classes require different facilities. Room design needed to accommodate the planned teaching strategies for collaborative learning and teamwork for both parts of the courses.

The basics instruction needed a facility that would: a) promote collaboration in teams of two or four, b) provide space for individual activity and computer access, and c) still support instructor presentations/lectures. The spaces for basics instruction needed to accommodate 36 seats per class for FEH. Given the number of sections of FEH that were being offered in 1999 and the rate at which the FEH program was growing, two classrooms were required. One of these classrooms is scheduled by FEH for 10 hours per day for four days each week. The other classroom is shared with Engineering Graphics and is used by FEH six hours per day for four days each week.

FEH has the goal of providing hands-on labs that represent the various engineering disciplines. These can include reverse engineering, measurements, building such things as circuits and gear trains, and taking measurements using instrumented devices such as bicycles and model rocket engine test stands. The laboratory experiments are done in groups of two or four. In addition to providing laboratory space for the hands-on experiments, the lab rooms have to accommodate teams doing design-build projects.

These facilities are a showplace for the College and the enrolled students take pride in being able to use them. The facilities help attract new students to the program. Figure 3 through 5 below show the room layout and table configurations for the first-year engineering classrooms and laboratories.

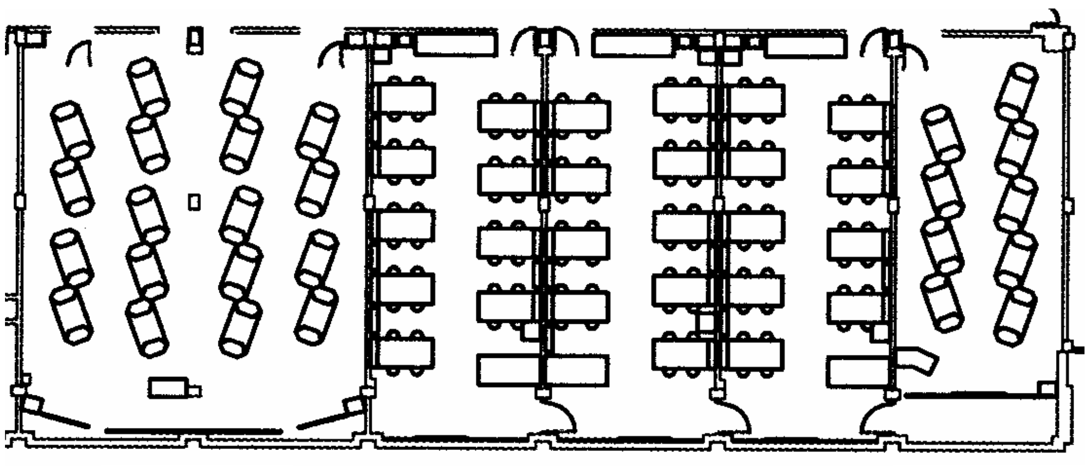

Figure 3. A floor plan of the classrooms and laboratory rooms used by the FEH and FE Programs

Figure 4. Photograph showing the classroom table layout.

Figure 5. Photograph showing the laboratory table layout.

6. Retention Results

As indicated in Figure 6 below, fewer than 40 percent of the beginning students who enrolled in engineering at The Ohio State University in Autumn Quarter of 1988 completed a degree in engineering. The data from the entering class of 1988 were collected for all students, not just those classified as "honors". This low retention rate, although typical of most engineering schools, was an impetus for development of the Gateway Pilot Program.

In the 1998 pilot of what is now called the Fundamentals of Engineering for Honors Program, honors students were divided into a control group and a group participating in the FEH program. As can be seen in Figure 3, the retention rate of students participating in the FEH program was about 15 percentage points higher than the retention rate for those in the control group at the end of the 5th year, by which time, almost all of the students had completed their BS degrees. In the 1999-2000 pilot, the same difference of about 15 percentage points can be seen between the program participants and control group through the fourth year.

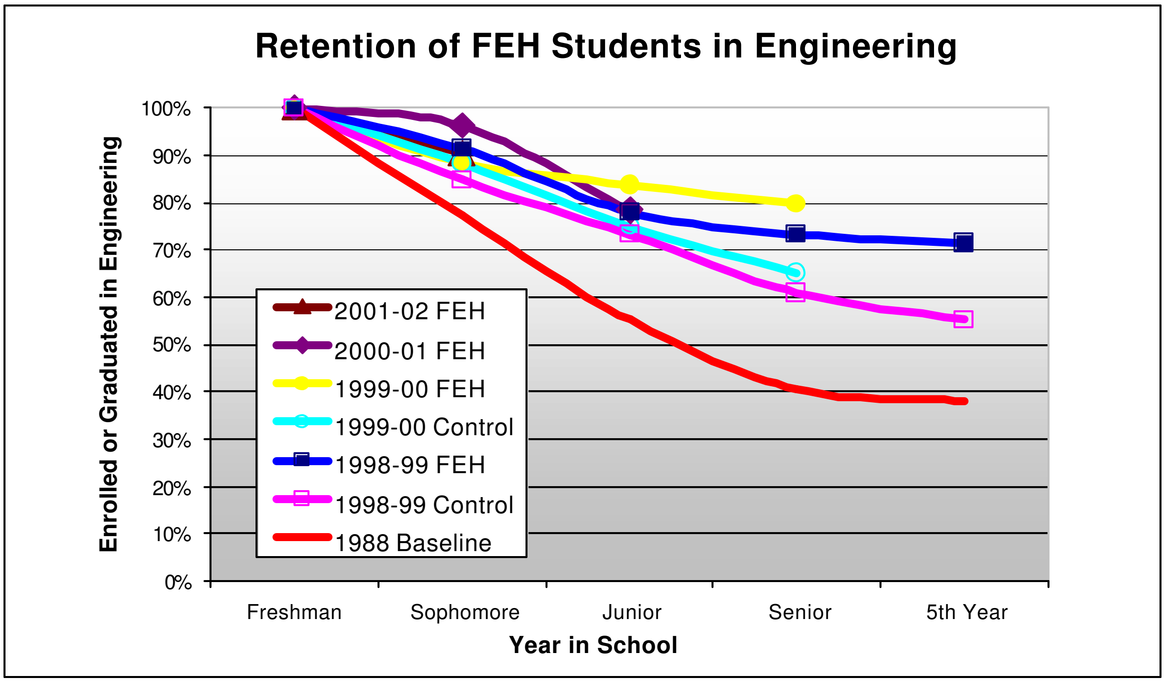

Figure 6. Retention of FEH and Non-FEH Honors Students in Engineering to Graduation Compared to a College Baseline for All Students Measured in 1988.

Student responses to surveys and student comments during informal conversations with faculty have provided insight into the factors that contributed to the increased retention rates for Freshman Engineering Honors Program participants. Almost all of the factors seem to be related to students' early development of a sense of belonging in engineering – a connection to the discipline, to the College of Engineering, to the engineering education process, and to the practice of engineering.

One of the basic tenets of the FEH was that students should have an opportunity to do hands-on engineering problem solving in their first term. People who go into engineering generally do so because they like to solve problems. Solving engineering problems in the first year can confirm that they have chosen the right major. The up-front engineering experiences gave the students an early connection to the discipline. A side benefit of having the hands-on engineering in the first year is that students who aren't enthusiastic about engineering, but were persuaded to enter the field anyway, learn quickly that engineering is not for them and can move to another discipline with little lost time.

The connection to the College of Engineering was made through people. FEH courses were taught by senior faculty members in the College of Engineering, with help from carefully selected graduate and undergraduate teaching assistants who were chosen for their understanding of the subject matter, dedication to teaching, ability to serve as peer mentors, and sheer enthusiasm for engineering. The instructional team used a student-centered approach and worked individually with students as needed. In addition, the FEH administrative staff and College advisors monitored the progress of each FEH student and intervened when a student appeared to be having difficulties with any of his or her courses.

Students in the FEH program were encouraged, in fact, required, to take an active role in their engineering education. Much of the course work was done in teams, and students learned early to help each other and to seek help from their teammates when it was needed. Students were required to provide continuing assessment by completing surveys and submitting electronic journals[24]. Faculty read what the students submitted and provided feedback, making changes in the course as appropriate. As a result, students had some ownership of the course and of their own education.

Finally, students in the FEH program had a connection to the practice of engineering. Industry supports the FEH program, providing funding, projects for students to complete, and internships for FEH alumni. Working with practicing engineers from industry reinforced the importance of the skills that students were learning in the FEH courses and provided incentives for the students to be even more diligent in their studies.

7. Recognition and Industry Response

In 1999, the College of Engineering recognized the team of FEH faculty (Engineering, Physics, and Mathematics) with the Boyer Award for Excellence in Teaching Innovation. The College of Engineering Ralph L. Boyer Award is presented to the faculty team or to an individual faculty member "who has made outstanding contributions to the improvement of undergraduate engineering education. The award recognizes the long-term impact of educational innovation to improve the overall quality of the undergraduate engineering education experience."

Industry has come to recognize that these FEH students are well prepared to participate in co-op or internships because of the course content that these first-year students have completed. Some of these companies have chosen to support the FEH program through funding and others have made contributions of time from their engineers. An example of the latter is Proctor & Gamble teaching a workshop on product launch to all of the sections of FEH. The list of companies includes American Electric Power, Arvin Meritor, AutoDesk, Caterpillar, Eaton, Ford, Honda, Lockheed-Martin, Lucent Technologies, Microsoft, Proctor & Gamble, Raytheon, and Texas Instruments. While the amount of funding provided is modest, currently about $25,000 per year, the contributions provide much-needed support for the operational expenses of the robot contest (facility and video equipment rental), funding to develop new hands-on experiments and new robot scenarios, funding for some of the costs of faculty and teaching associate training, and other program enhancements not otherwise supported by the College. In addition, it is a clear signal that industry values the program.

8. Conclusions and Future Plans

The Fundamentals of Engineering for Honors program has been a success for the College of Engineering. The retention of the best Engineering students is up significantly – from 50 to 60 percent to more than 70 %. The FEH program helps recruit very good students (ACT Composite 29 or above – top ten percent HS class rank) for the College. Industry seeks out these students early in their undergraduate program for co-op and internship jobs. Industry partners also contribute funds to the program for operation and development of new laboratory experiences and of instructional innovation. Early tracking of FEH students showed that they performed better in subsequent math and physics courses than their matched control group students.

An FE program (required for all students) was developed from the FEH program. While not as challenging as the FEH program, the FE program contains almost all of the same elements as the FEH program. Retention for all students to earning a degree in Engineering is up from 38 percent in 1988 to more than 60 percent in 2003.

The FEH program has drawn the Engineering, Physics and Mathematics faculty closer. The future will be focused on continuous improvement of the teaching teams and student learning, on making and keeping ties to industry, and incorporating new technology and new methodology for more effective and efficient instructional delivery. Faculty development is a key component of the program, and the program staff will continue to plan and carry out workshops and weekly training to improve the learning environment.

The Career Services office in the College of Engineering allows FEH students to register and interview with companies after one quarter. Non-honors students may register and interview with companies after completing the FE two-course sequence.

9. Acknowledgements

Gateway Engineering Education Coalition – Funded by the National Science Foundation.
Without the initial funding from NSF, it is doubtful that this program would have been so well developed. The early funding allowed planning and piloting to take place and then allowed the modifications and improvement over the first three to four years

Contributors. The authors wish to gratefully thank the following Ohio State faculty, staff, and students for their contributions to the FEH program. Individually, each took ownership of this FEH program, and all helped the students in the program feel like they were part of the program and the College.

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Gary Maul	Ind. & Sys. Engineering	Hands-On Labs, Design-Build Project
Prabal Dutta (UG)	Electrical Engineering	Robots for Design-Build
George Staab	Engineering Mechanics	Math-Mechanics Collaboration
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John Merrill	Engineering College	Assessment and Evaluation, Administration
Fritz Meyers	Engineering Graphics	Graphics and CAD
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