Educating Engineers for the Information Age

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Abstract

Information technology, which is rapidly becoming one of the fundamentals of engineering, will soon be embedded in virtually every new product and process. In order to take full advantage of the wide range of new possibilities that are becoming available, the design of products, systems, and services will require teams that can integrate information technologies with traditional engineering areas such as fluid mechanics, thermal sciences, materials science, manufacturing technologies, and precision design. In addition, more than 1.3 million new programmers, engineers, systems analysts, and computer scientists will be required between 1996 to 2006 to meet the information technology demands of the nation's industries according to a report from the U.S. Commerce Department's Office of Technology.

To address this need, the vital importance of the introduction of information technologies to creatively improve undergraduate education has been stressed by the Carnegie Foundation for the Advancement of Teaching.

Thus, in partnership with relevant industries, we have developed instructional materials in the form of multi-media case studies with the following educational objectives: (1) to introduce engineering students to the complexity of real-world problems; (2) to show how engineering companies operate in the information age; and (3) to improve the higher-level cognitive-based problem solving abilities of our students.

In this paper, we will describe our approach and discuss how the educational objectives were accomplished. Our results show that multimedia case studies (1) stimulate students' interest in engineering topics, (2) engage female students, and (3) motivate engineering faculty members to integrate these materials in their classrooms.

I. Introduction

Contemporary engineering design and industrial practice has undergone a dramatic change in the new information age, where the machinery, processes, control systems, and services are information technology-driven. We use the term information technology (IT) to refer to any use of machine technology that is controlled by or uses information in some important way. Information technologies are a combination of hardware, software, and telecommunications networks that people build and use to collect, create, and distribute data. For example, one type of information technology is a programmable robot on the shop floor of a manufacturing firm that receives component specifications and operational instructions from computer-based databases and expert systems. Another example would be a computer-controlled drill press combined with other shop floor equipment in such a way that a person could monitor and control each piece of

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equipment from a separate, possibly remote, computer (Jessup and Valachich, 1999).

Future innovations are expected to increasingly exploit synergies between information technologies and engineering disciplines (Suh, 2000). The fundamentals of engineering must now include information technology, which will be embedded in virtually every new product and process (Wulf, 1998). In order to take full advantage of the new opportunities that are opening up, the design of products, systems, and services will require teams that can integrate information technologies with traditional engineering areas, such as fluid mechanics, thermal sciences, materials science, manufacturing technologies, and precision design. In addition, more than 1.3 million new programmers, engineers, systems analysts, and computer scientists will be required between 1996 to 2006 to meet the nation's information technology demands, according to a report from the U.S. Commerce Department's Office of Technology (1998). The need to use information technologies to creatively improve undergraduate education has been highlighted by the Carnegie Foundation for the Advancement of Teaching (Fortenberry, 2000).

How has the education establishment reacted to the need to better educate engineering students for the information age? The National Science Board reports that the number of science and engineering students is dwindling and the shortage of technically skilled workers is rapidly becoming critical (National Science Board, 2000). U.S. universities lose 40 percent of the freshmen admitted to engineering programs by the end of their sophomore year and employers chide schools for not providing the skills needed (Prados and Proctor, 2000). These observations show that the education establishment is not doing an adequate job of educating engineering students for the information age. In our opinion, a major reason for this is due to lack of appropriate educational materials that bridge the gap between theory and practice are not available to teachers. The Laboratory for Innovative Technology and Engineering Education (LITEE) at Auburn University has therefore embarked on a project to develop these educational materials. This paper discusses the development of the new educational materials and the results of their evaluation in the classroom.

2. Goals and Educational Objectives of the Project

Information technology is essential for solving critical national problems in areas such as science and engineering, the environment, health care, and government operations, but a fundamental understanding of how it can best be applied is required to make optimal progress (National Science Foundation, 1999). Recognizing this change in industry expectations, various institutions are seriously looking into modifying their curriculum (Sorsby et al., 1999). For example, the mechanical engineering department at MIT has been transforming the undergraduate mechanical engineering curricula from one primarily based on physics to one based on a combination of physics, information science, and biology (Suh, 2000). **Therefore, the first goal of this project is to develop course materials that introduce engineering students to the complexity of real-world problems and show how engineering companies operate in the information age. Based on this goal, educational objectives that the course materials need to achieve were derived. These are shown in Table 1.**

The teaching of domain-specific knowledge has long been recognized to be the primary objective of school and college education, but many students lack the breadth of knowledge and skills that are fundamental to the practice of their profession (Raju and Sankar, 1999; Aldridge and Benefield, 1997; Fergusson, 1992). There is now a growing awareness among educators of the need to place a greater emphasis on imparting higher-level cognitive skills such as reasoning,

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critical thinking, decision making, problem identification, and problem solving. A variety of national reports (National Science Board, 2000; Fortenberry, 2000; Boyer, 1987; National Science Foundation, 1996) have also stressed the importance of teaching such skills to all levels of students. **Therefore, the second goal of this project is to develop course materials that will improve students' higher-level cognitive-based skills. Based on this goal, educational objectives that the course materials need to achieve were derived. These are shown in Table 1.**

In the workplace, engineers and managers increasingly work in teams and use information technologies to interact virtually when team members are located at distant sites. It is critical to provide a similar experience to engineering students so that they are better prepared for work in the information age. **Therefore, the third goal of this project is to develop multi-media/web-based materials that show how teams of engineers and managers solve real-world problems. Based on this goal, educational objectives that the course materials need to achieve were derived. These are shown in Table 1.**

Project Goals (What will we do?)	**Educational Objectives (What will students achieve?)**
Develop course materials that introduce engineering students to the complexity of real-world problems and show how engineering companies work in the information age	*The students will be expected to:* *- learn how companies embed information technologies in the design of products and systems and start using the technologies to a limited extent.* *- learn how companies incorporate decision-making software to improve engineering decision-making and start using the software to a limited extent.* *- work in teams, thereby enhancing their team building, interaction, and interdisciplinary skills.*
Develop course materials that will improve students' higher-level skills.	*The students will be expected to:* *- identify appropriate criteria for solving problems in unstructured situations* *- analyze alternatives given multiple criteria* *- differentiate between alternatives* *- evaluate alternatives* *- synthesize relevant materials into defensible solutions to problems* *- present a solution persuasively* *- be actively involved in learning situations*
Develop multi-media/ web-based materials that show how engineers and managers solve real-world problems.	*The students will experience:* *- Synchronous learning opportunities, such as triggering learning interest, learning from others, and working in teams.* *- Asynchronous learning opportunities, such as solving challenging problems, accessing vast information sources, learning discovery-based educational experiences safely, and enhancing peer-to-peer education.*

Table 1: Educational Objectives to Achieve Project Goals

3. Development of Case Studies

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A review of the literature showed that the teaching methodologies of lectures, experimental laboratories, design projects, case studies, games, and internships could all be used to achieve the project goals. An analysis of the use of these methodologies, along with the results from earlier evaluations of the use of case studies in engineering classrooms, showed that case studies are the best candidate for meeting the educational objectives (Raju and Sankar, 1999).

A case is typically a record of a real-world problem that has been faced by engineers or managers, together with the surrounding facts, opinions, and prejudices upon which decisions have to depend. These real and particular cases are then presented to students for considered analyses, open discussion, and final decision as to the type of action that should be taken (Naumes and Naumes, 2000). After the students have arrived at a solution, their decisions, results, or proposals are compared to the solution that was actually adopted by the company that originally experienced the problem.

A review of the past issues of Frontiers of Education Conference and the ASEE Conference reveals that very few appropriate case studies are available for use in engineering classrooms. Examining the courseware used by engineering educators, as shown in the NEEDS (NSF's National Engineering Education Delivery System) database, reveals the use of very few case studies in engineering education. Most of the case studies and courseware available in the database teaches the students domain-specific knowledge and is not designed for improving higher-level cognitive skills. Overall, there is a lack of case studies that integrate information technology issues into engineering design, theory, and practice.

We developed three case studies: *Crist Power Plant*, *Briggs and Stratton*, and *Powertel* in order to meet the objectives shown in Table 1. In the next section, we will discuss the details of the Crist power plant case study and use it to show how information technology tools are used in the real-world. We also provide a brief overview of the other two case studies. .

3.1. The Crist Power Plant case study.

We worked closely with the Gulf Power Company to create a written case study, video, and CD-ROMs as part of our project. The objectives of the Crist case study were to teach the students:

(a) the technical and project management details involved in planning and implementing a real-world project,

(b) the importance of developing and prioritizing project criteria in analyzing alternatives, and

(c) how to embed an expert system in the decision-making process.

The authors discussed with the plant manager the maintenance and planning schedules of a turbine-generator unit in the plant in several sessions during the period January to August of 1997. We then visited the plant and observed the actual implementation of the decision from January to March 1998. The information gathered in these discussions and visits was used to create two videos and a multimedia CD-ROM that show the problem and the actual implementation of the decision. The problem addressed in this case study is described below:

> Joe, the plant manager, had to choose an alternative for implementation during the next year's planned maintenance shutdown of turbine generator unit #4. The unit to be maintained was put into operation during 1959 and had been vibrating excessively and giving problems in the operation of its generator rotor, stator, and retaining rings. The

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management team had come up with five alternative ways of addressing the problem. They generated a table that showed all the alternatives and the costs associated with each. Each alternative offered a different combination of options, as well as varying costs (Table 2).

Table 2: The Alternative Solutions Proposed and Their Associated Costs

Alterna-tives	Use of the 1960's stator bars	Install new stator bars	Block and repair rotor	Buy spare rotor with retaining rings	Replacing retaining rings	New generator set	Labor costs	Overall costs
1	$550,000	---	$150,000	---	$300,000	---	$200,000	$1,210,000
2	---	$850,000	$150,000	---	$300,000	---	$110,000	$1,410,000
3	$550,000	---	---	$633,000	---	---	$117,000	$1,300,000
4	---	$850,000	---	$633,000	---	---	$117,000	$1,600,000
5	---	---	---	---	---	$1,800,000	$500,000	$2,300,000

Mark, from Information Services, had worked with Jimmy, the Superintendent of Engineering and Administration, and prioritized the alternatives using a Decision Support System called *Expert Choice*. This software is based on the theory of Analytic Hierarchy Process (Saaty, 1994). It is designed to assist a decision maker in solving complex problems that involve many criteria and several possible courses of action. It provides the tools to construct decision frameworks for both routine and non-routine problems and to utilize these decision frameworks in ways that include value judgments. Using this software, Mark identified the goals, alternatives, criteria and sub-criteria involved in making the decision (Table 3). After developing the model, the next step was to compare the criteria of cost and risk, then compare the sub-criteria against each other and finally compare the alternatives under each sub-criterion. Finally, Mark used the model to evaluate the relative worth of each alternative. The Expert Choice model synthesizes the weights that were derived for all the criteria and sub-criteria and using the principles of Alternative Hierarchy Process, derived overall priorities and rankings for the alternatives. Table 4 shows the performance graph provided by the Expert Choice model for this problem. This shows that alternative 4 is preferred since it has a priority of 23.7%.

After seeing the charts, the plant manager commented:

> We are paid to make the final judgement and have to make the best decision given the age of the unit, goals for the plant and the position of unit #4 on the dispatch list. The charts from the Decision Support System can only guide us, not make the decision for us. Top management is watching how all of us respond to the planned maintenance of this unit given the new competitive pressures facing the company. If we can make this unit work for many more years with minimum maintenance costs, the overall cost of producing power from Crist would be lower compared to the other power plants in Southern Company. That would be a highly desirable

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consequence given the pressures of deregulation of the power industry.

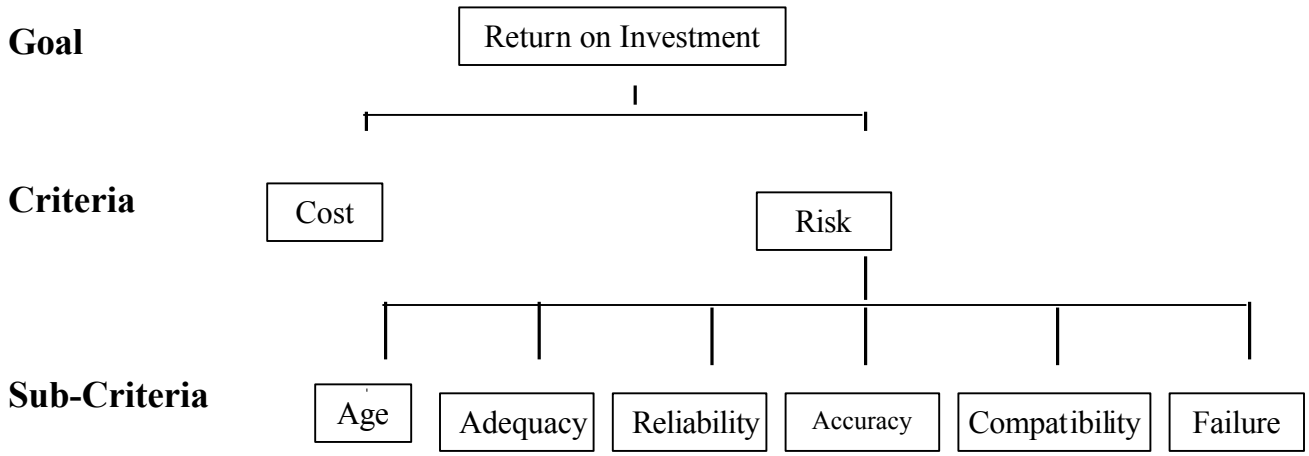

Table 3: An Expert Choice Model for the Crist Power Plant Problem

40% RISK	
	23.7% for alternative 4
60% COST	**20.8% for alternative 3**

Table 4: Sensitivity Analysis When Risk is Weighted at 40% and Cost at 60%

A CD-ROM was developed that showed videos of the managers discussing the problem, included photographs of the parts used in the case study (such as rotor, stator, retaining ring, turbine-generator set), showed connection between science, math, engineering, and technology (STEM) topics to the case study, and provided the Expert Choice software so that the students can perform sensitivity analysis.

3.2. The Briggs & Stratton case study

Briggs & Stratton sold the K08 engine, a popular premium 11 horsepower cool-bore engine, successfully for over 25 years; however, the company planned to retire this model in 2002 because it failed to meet emission standards. In order to stay in business and to meet the California EPA (Environmental Protection Agency) and ARB (Air Resource Board) emission regulations, the K08 engine had to be replaced.

Therefore, in 1993 Briggs & Stratton planned to introduce a new engine, the K11, a 13 horsepower cool-bore (aluminum) engine to be released by 1998, so that the K08 engine could be phased out by 2002. The K11 engine was designed and developed between 1993 and 1998. However, during its emission tests in 1998, the K11 engine also failed to pass. Data confirmed that there were problems due to an improper amount of oil consumption and exhaust release. Therefore, the new engine had to be fully redesigned and was not released into the market until late 2001. The life cycle of developing the K11 engine was thus four years longer than expected. The plant management wanted to know why and asked for a thorough examination of the

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processes and information systems used by the company.

The case study was developed to incorporate the following objectives.:

- Show the practices in development, design, and manufacturing process for Briggs & Stratton's product life cycle. The students must use the flowchart provided in the case study material by Briggs & Stratton to analyze the development of the K11 engine.
- Identify where different information systems, including SAP R/3, are used in the enterprise and how they work together to achieve organizational objectives.
- Illustrate how changes in engineering design/test results may result in changes in market release of a product, thereby impacting long-term business plans.

3.3. The Powertel case study

The marketing department of Powertel, a cell phone company, introduced a new rate plan which brought in so many new customers that it put a severe strain on their existing network. One of the worst centers of congestion arose due to the heavy traffic at the intersection of Interstate 459 and Highway 280 in Birmingham, AL. Powertel's Vice President for Operations was aware of the strain on the network and asked his colleagues for recommendations on how to handle the increased traffic. The question was not if, but where to build a new cell site to handle the increased traffic. The company could add the new antennas and other necessary equipment at either of their two existing sites: on the roof of the Sheraton Hotel or on the Summit. The Vice President had to make an economically sound decision that also made engineering sense. For this company, the cost of erecting cell sites consumes approximately 80% of the annual budget and any errors in cell site location would have a major impact on call completion rates.

In the words of the Vice President, "It's a classical engineering/ marketing/ economic problem." For engineering students, this case enhances their knowledge about frequency reuse, CAD drawings, performance graphs of cell sites, honey comb models of frequency reuse, propagation of radio frequencies, and cell coverage of frequency. Business students have an opportunity to analyze the impact of marketing and economics on the cost involved in building the cell site versus the cost of losing customer goodwill.

4. Evaluation of the Effectiveness of Case Studies in Achieving Educational Objectives

The Crist case study was tested in engineering and business courses with about 300 students and in a workshop with 25 engineering educators. Details of the evaluation results for this case study have already been published (Halpin, Halpin, and Good, 2000; Mbarika, Sankar, and Raju, 2003; Raju, Sankar, Halpin, and Halpin, 2002). We provide a summary of these evaluation efforts. The other two case studies, Briggs & Stratton and Powertel, have recently been introduced in undergraduate classes at Auburn University and an evaluation of their effectiveness will be reported in the conference.

The evaluation of the Crist Power Plant case study could be summarized under four major categories:

(a) Perceptual evaluation of effectiveness by students
(b) Differences between engineering and business students
(c) Differences between male and female students

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(d) Perceptual evaluations by faculty members

Perceptual Evaluation of Effectiveness by Students

The evaluation (Halpin, Halpin, and Good, 2000) of the Crist Power Plant case study was performed, when students in an engineering design class completed two evaluation surveys. In addition, an evaluation was performed when this case study was presented to engineering educators at a workshop in Auburn, Alabama, during May 2000. Both students and educators were enthusiastic in their response to the case studies. The details of the evaluation are not provided here and available in the reference cited above.

Differences between Engineering and Business Students

We initially ran the Crist Case Study without providing access to the Expert Choice software or its results during 1998 and 1999 in both engineering and business classrooms (Sankar et al., 1997; Sankar and Raju, 2001). We noticed that business students tended to prefer alternative 5, which meant buying a new turbine-generator unit for the plant. Based on their comments, they appeared to choose this option because they were reluctant to repair specific parts of the unit; they found it easier to simply replace it, thereby solving the problem without having to thoroughly analyze the problem. Engineering students, on the other hand, usually chose options 3 or 4, which were much closer to the solution actually selected by the plant manager. However, they had difficulty in communicating their choice to a non-technical manager and convincing him/her to go with the option they chose. This is the reason why we obtained an agreement with Expert Choice Inc., to incorporate their software in the CD-ROM.

The modified case study incorporating Expert Choice was run during the winter and spring quarters of 2000 in both engineering and business classes. As shown earlier, the expert choice software recommended choosing either option 3 or option 4. Once they learned how to work with the software, both sets of students generally chose either option 3 or option 4 and were able to provide excellent reasons why their selection was the correct one. This result shows that without exposure to case studies that integrate business, information technology, and engineering issues, future business leaders tend to choose simpler solutions rather than the most cost-effective solutions. The software also helped engineering students to communicate effectively with a non-technical manager, allowing them to provide the scientific foundation for their decision when solving complex technical problems.

Differences between Male and Female Students

In another study related to evaluation of Crist Power Plant case study (Mbarika, Sankar, and Raju, 2003), a research model was developed to show the potential relationships between gender and higher-level cognitive skill improvement with two intervening variables of learning-driven factors (including the constructs of learning interest, challenging, self-reported learning, and learning from others) and content-driven factors (including the constructs of quality, locatability, ease of use, and timeliness). Two questionnaires collected information from 140 students who participated in the experiment (99 men and 41 women). A structural equations model was used to compute the coefficients of the relationship indicated in the research model.

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An analysis of the results from the model shows that while both groups perceived an improvement in the learning-driven factor, female students valued the learning-driven factor more highly than their male counterparts. This implies that when designing new learning environments, it is particularly important for female students to be challenged and have opportunities to learn both by themselves and from others. These results should be taken into consideration when designing new teaching programs.

Perceptual Evaluation by Faculty Members

We also tested the Crist case study in a series of focused workshops, with the pilot session held during May 2000, with the assistance of sponsorship from the National Science Foundation. The primary objective of these workshops was to provide faculty with an opportunity to gain hands-on experience using multimedia case studies. The feedback and evaluations from the workshops were extremely positive, and we have now formed partnerships with faculty members at several universities in order to disseminate these educational materials. The participants enjoyed the program, facilities, energy and excitement of workshop members, and felt the workshops were unique and important in disseminating the type of innovative instructional materials that can bring real-world issues into classrooms. We concluded that "focused workshops" are an excellent means of disseminating innovative educational materials (Raju, Sankar, Halpin, and Halpin, 2002).

5. Summary and Conclusions

Table 5 shows the goals of the proposed project, how they were incorporated in the Crist Power Plant case study, and the evaluation results from both the students and the engineering educators. The students found the Crist Power Plant case study to be a provocative and useful educational tool. Both the comments and the evaluation results indicated that students reacted favorably to the Crist Power Plant case study and the use of Expert Choice as an instructional tool. These results show that the case studies developed by LITEE successfully introduce engineering students to the complexity of real-world problems, show how engineering companies operate in the real-world, and improve the higher-level skills of the students.

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Proposed Project Goals (What will we do?)	How did the Project Achieve the Goals?	Evaluation in Engineering Classes and a Workshop for Engineering Educators

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Develop course materials that introduce engineering students to the complexity of real-world problems and how engineering companies operate in the information age	The Crist Power Plant case study was a $2.0 million project planned over two years and executed in three months. Expert Choice was used to help in the decision-making process.	Students found the case study to be relevant and useful, and important and valuable. A prominent theme based on an analysis of their comments was the real-life context of the problem, replete with open-ended possibilities and multiple solutions. The engineering educators found the case study to be interesting and exciting, important and valuable, instructionally helpful, relevant, and useful.
Develop course materials to improve higher-level cognitive-based problem solving by students.	Used case study methodology and provided opportunities for students to play the roles of engineers and managers.	Students reported greater perceptions of skill development, learning, intrinsic learning and motivation, communication skills, and opportunity to learn from fellow students. In particular, female students reported an improved in their higher-level cognitive skills due to an improvement in learning-driven factor.
Develop multi-media/ web-based materials that show how teams of engineers and managers solve real-world problems.	Developed a CD-ROM which captured the planning and implementation of the project through videos and photos. A copy of the Expert Choice software was provided in order to give the students hands-on experience.	The students found the case study to be a provocative and useful Another prominent theme identified by students was the incorporation of software. Students valued the "use of DSS software," "the use of Expert Choice," and "using the Internet."

Table 5: Evaluation Results of the Crist Case Study Project

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Dr. Raju is a member of the ASME, ASEE, INCE, ASA, ASNT, INCE. He served on the executive committee (1992-1996), and as Chairman of the ASME Noise Control and Acoustics Division (1996-1997), and served as Assistant Vice President Region XI (1994-1995). He also served as president of the Alpha Upsilon Chapter of Phi Beta Delta, Honor Society for International Scholars (1996-1997). He can be contacted at pkraju@eng.auburn.edu.

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Dr. Sankar is a Co-Principal-Investigator in four grants sponsored by the National Science Foundation, Division of Undergraduate Education, to develop course material that brings theory and practice together in engineering classrooms. He leads a team of undergraduate and graduate business students who along with engineering students are creating written and multi-media case studies with help from industries. A CD-ROM courseware co-developed by him called, "Della Steam Plant," won the 1998 Premier Award for Engineering Education Courseware for its ability to develop higher-level cognitive skills such as problem identification, critical thinking, and problem solving in the students. He has won grants from the Thomas Walter Center for Technology Management, the College of Business, and the Office of the Provost in order to improve the education of undergraduate students.

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