The Evolution and Evaluation of an Interactive Engineering Design Teaching Tool: MIT's EDICS

by

Craig Edward Jimenez

Submitted to the Department of Mechanical Engineering
in partial fulfillment of the requirements for the degree of

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Author..
Department of Mechanical Engineering
January 6, 2006

Certified by...
David Gordon Wilson
Professor Emeritus
Thesis Supervisor

Accepted by..
Lallit Anand
Chairman, Department Committee on Graduate Students

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Abstract

For this thesis, I refined and tested a computer-based engineering teaching tool called EDICS. EDICS (Engineering Design Instructional Computer Program) has proven to be a fun and intriguing means of conveying a wide variety of engineering design subjects to undergraduate students. The core audience of EDICS was assumed to be undergraduate engineering students who lacked the practical experience of manipulating common mechanical components and devices. It has been discovered, though, that EDICS is a useful tool for nearly all types of engineering students at many different levels of experience. The testing of EDICS was carried out by having students study either short excerpts from the program or similar subjects covered either in a popular textbook or a booklet, then testing their knowledge retention by subjecting them to a short, written exam. The subjects that were studied were: transmissions, fastening and joining techniques, and engineering drawing and drafting. The results of this evaluation show that in the subjects of transmissions and fastening and joining, students who used EDICS to study performed significantly better than those who studied using paper-based materials. In the subject of engineering drawing and drafting, the students using EDICS scored, on average, better than the students using the paper-based materials, but the difference was found to be not statistically significant.

Thesis Supervisor: David Gordon Wilson

Title: Professor Emeritus

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I would like to thank my thesis advisor, David Gordon Wilson, for his patience and assistance in both improving EDICS and testing its effectiveness. I would also like to thank my friends, who have made my time here at MIT a lot more fun and a little less stressful.

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Chapter 1

Introduction

EDICS (Engineering Design Instructional Computer System) is a media-based teaching tool designed to improve students' general engineering design skills and bolster their overall confidence level. It was developed and refined by two MIT faculty members and several graduate and undergraduate students over the past seventeen years, with David Gordon Wilson, professor of mechanical engineering, acting as primary investigator.

In 1988, the full development of EDICS began through a grant from the National Science Foundation with the intent of enabling "motivated but relatively inexperienced mechanical-engineering students to catch up with their better-prepared classmates" [21]. In its early existence, EDICS was comprised of three sections: bearings, mounting of shafts to rotors, and connections between cylinders. The creators of EDICS chose these three topics because of their prevalence in most engineering designs and their ability to cause problems for a large number of students. At MIT in the late 1980s, it was evident from studying students' work in senior-level design courses that there were an ever-present number of graduating mechanical-engineering students who lacked the knowledge and experience to skillfully design many basic mechanical components and connections. In general, students across the country were continuously having difficulty making the transition from engineering theory to engineering practice [6]. Thus EDICS was designed to be an effective tool to give these students the proper level of education they deserved. Engineering design is often overlooked as a concrete area of study due to its interconnectedness with other subjects and the difficulty one faces when trying to teach it using conventional instruction methods. In the words of Evans et al. in 1990: "The subject [of design] seems to occupy the top drawer of a Pandora's box of controversial curriculum matters, a box often opened only as accreditation time approaches. Even 'design' faculty - those often segregated from 'analysis' faculty by the courses they teach - have trouble articulating this elusive creature called *design*" [9].

During the early stages of development, the creators of EDICS envisioned a relatively small scope for the program. However, as work on EDICS continued and word of the program and its purpose spread, its audience became larger and more diverse. Originally intended for use with MIT's young mechanical engineering students, the program blossomed into a tool used around the world not only by engineering students, but by many individuals who are simply interested in the subject of mechanical design. A testament to the extent of EDICS' audience may be found in its popularity in several parts of Africa. Amy Smith, a former graduate student at MIT who worked with an early version of EDICS, once took the program to various African countries after participating in the Peace Corps for four years in Botswana. The program was well-received with many teachers and principals who showed a strong desire to have the program be made widely available. It was decided, however, that some parts of EDICS were not suitable for such far-reaching distribution due to various cultural differences.

1.1 Multimedia Teaching Tools

As one may expect, there exists a large number of multimedia teaching tools that cover a wide variety of subjects. For example, MIT professor of civil and mechanical engineering Chiang C. Mei has led extensive research in creating a "coordinated sequence of modular subjects" dealing with fluid mechanics. The goal of the project is to replace the often redundant courses on fluid mechanics taught in multiple departments with an interdisciplinary and interactive computer program available to students online [17]. Another example that shares an idea related to EDICS, although not nearly as comprehensive, once existed at the University of California at Berkeley in the course ME39C. The course, now no longer offered, was titled "Multimedia Case Studies of Engineering Design," and its goal was to introduce a wide variety of concepts and good design practices to incoming freshman engineering students. In the course, students authored media-based CD-ROMs that contained various case studies relating to engineering design [12].

Many media-based programs for teaching specific aspects of science and engineering, such as drafting, thermodynamics, and engineering physics, are also being used throughout the world. For example, professors from the University of Trnava and the Slovak University of Technology, both located in the Slovak Republic, have authored a media-based CD-ROM to supplement traditional textbooks in an introductory engineering physics course. The program is similar to EDICS in that it contains interactive animations, multiple choice tests, and a glossary; it is, however, much narrower in scope, covering only the subject of engineering physics [19]. Another example that is closely related to a portion of EDICS is the multimedia computer-based software created in China for teaching engineering drawing. Professors at the Guangdong University of Technology have created a software package containing lessons, exercises, tests, and feedback for the students. The program is filled with impressive graphics, and offers students a more exciting view of the subject of engineering drawing and computer-aided drafting [23].

All the multimedia teaching tools described above fall into the categories of either subject-based tutoring tools or brief overviews of the engineering design process. EDICS, on the other hand, since its treatment of engineering design is fairly comprehensive and detailed, does not entirely fit into either of these categories. EDICS can thus be said to be an original and innovative multimedia teaching tool for mechanical-engineering design.

1.2 Revisions of EDICS

Since its initial release, Wilson and a number of graduate students have made some significant revisions and additions to EDICS. In 1992, graduate student Sepehr Kiani created a new chapter that dealt with engineering drawing and drafting. In 2003, graduate student Melody Yung produced a chapter on various fastening and joining techniques [22]. Presently, EDICS covers the three original subjects, as well as drawing and drafting, fastening and joining, transmissions, and material selection, for a total of seven independent chapters. The transmission and material selection chapters were compiled and added by the author of this thesis between 2004 and late 2005. The content found in these chapters is an amalgamation of material found in textbooks and on websites, as well as original information supplied by David Gordon Wilson and the author. Throughout the course of the most recent revision, various other chapters of EDICS were also updated to provide users with a more succinct, informative program. The main menu of EDICS, from which one may navigate to any of the seven chapters, can be seen below in Figure 1. The broad range of topics covered and the detailed descriptions and examples presented in each chapter can satisfactorily supplement the material presented in most introductory engineering design courses.

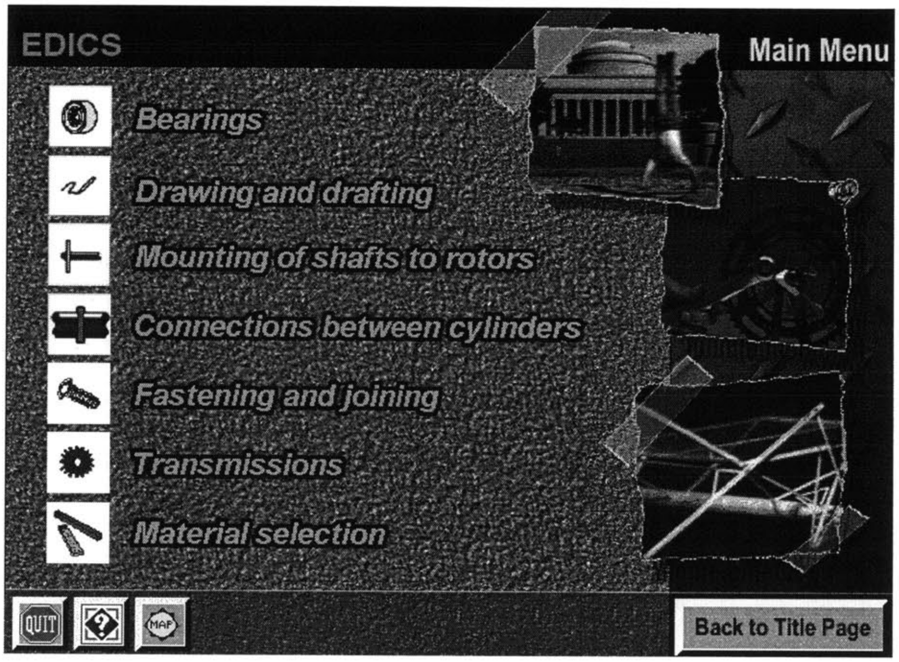

Figure 1: Main menu of EDICS

Another significant improvement to EDICS was the overhaul it received by Amy Smith and Melody Yung to make it compatible with modern computing equipment [22]. In its original form, EDICS was compatible only with Apple's Macintosh computer, and needed a laser-disc player in addition to the computer monitor to view many of the images and videos. Since then, there have been remarkable improvements in computers and digital media, with laser-disc technology becoming nearly obsolete. Currently, EDICS is fully compatible with both the Mac and PC and is available either through the internet or on a single CD-ROM.

Chapter 2

A Walkthrough of EDICS

EDICS is divided into seven chapters: bearings, drawing and drafting, mounting of shafts to rotors, connections between cylinders, fastening and joining, transmissions, and material selection. Most chapters are then subdivided into nine sections, which consist of an explanation of the physics involved with the subject, some good design practices, several examples, and various other resources and information. The seven chapters, as well as some of the unique and helpful material found within them, are described briefly below.

2.1 Bearings

The bearings chapter of EDICS introduces the student to various types of bearings, and lets the student examine several applications of bearings in real-world situations. The concept of constrained relative motion is discussed early on in the chapter, and various loading conditions and their corresponding failure modes are analyzed throughout. This chapter is unique in the fact that it is perhaps the most interactive of the seven chapters, featuring animations, games, and several short quizzes and trivia questions. In the section concerning design specifications of bearings, there is an interactive selection system that allows the user to specify several conditions and dimensions of a bearing, then produces an array of possible bearing types that may be used for the specified design situation. This chapter also contains one of EDICS' more amusing activities entitled "Find the bearings." In this activity, the user must correctly identify all the bearings in a short cartoon animation appearing on the screen by clicking on different parts of the image. If all the bearings are correctly identified, the user is congratulated by either a round of applause or a heavenly-sounding "Hallelujah!"

2.2 Drawing and drafting

Several engineering drawing techniques and conventions are identified in the drawing-and-drafting chapter of EDICS. The format of this chapter is slightly different than the other six due to the highly visual nature of the subject matter. Instead of nine sections within the chapter, the user is directed into four sections dealing with topics such as dimensions, cross-sections, and tolerances. The various animations and visual aids within this chapter have been identified by students as very useful in helping with three-dimensional visualization and transformation skills. The layout and styling of this chapter, as seen below in Figure 2, is also slightly different than the other six, portraying an appearance somewhat reminiscent of a sketch of a part or assembly, which is consistent with the subject matter of the chapter.

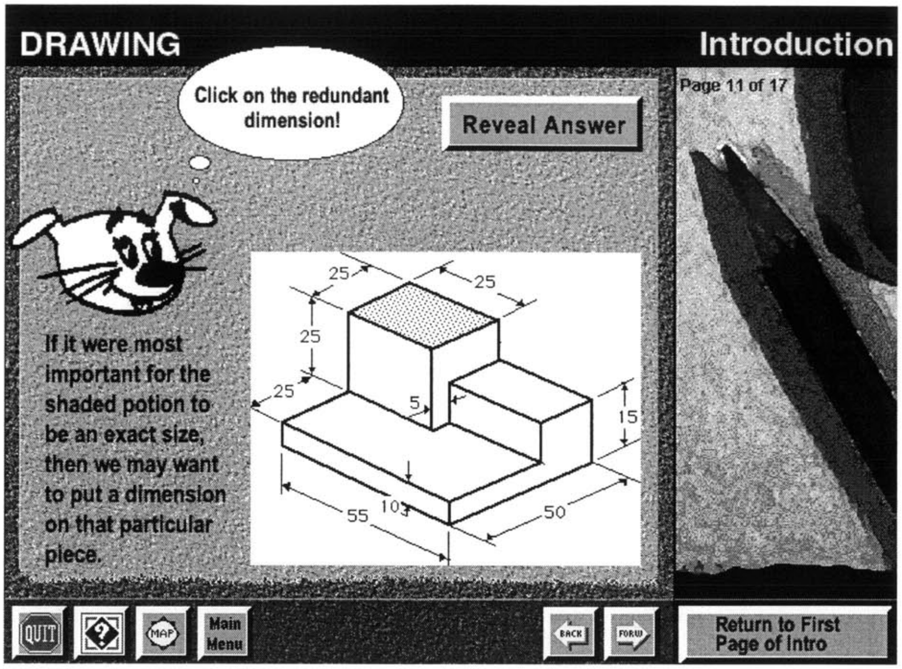

Figure 2: EDICS drawing chapter

2.3 Mounting of shafts to rotors

One of the original three chapters of EDICS, the mounting-of-shafts-to-rotors chapter is also one of the most practical. Designing a connection between a rotor and a shaft may seem simple at first, but the fact that many senior-level engineering students were finding it difficult to do successfully is testament to the fact that it is often quite problematic. Several aspects of good shaft-to-rotor connections are introduced to the user in this chapter, but perhaps even more helpful to the user are the plentiful examples that are given throughout the many sections. In nearly every section, examples portraying both good and poor design decisions are shown, allowing the user to begin developing and refining his or her engineering intuition. The user is also shown an array of proven shaft-to-rotor-connection types, each one accompanied by a description of the pros and cons involved in using it and the manufacturing techniques used to create it. This chapter also contains a multiple-choice test to allow the user to test his or her knowledge of the concepts. The bearings chapter and the chapter on connections between cylinders also contain a self-test for review of their respective material.

2.4 Connections between cylinders

This chapter introduces the user to the many techniques for connecting and capping cylinders. Similar in its layout and styling to the chapter on the mounting of shafts to rotors, the chapter on connection between cylinders is also similar in its high level of applicability. Several possible modes of failure are examined in the physics section, including buckling of long extended cylinders and shearing of cylinders carrying torque. This chapter also provides an interactive selection system similar to that in the bearings chapter. The user is asked to specify use, shape, and size of the cylinder connection, then is given several types of connection methods to employ for that particular circumstance. The examples section contains by far the largest number of examples when compared to similar sections in other EDICS chapters. The section describes 34 different types of connections, most which are accompanied by multiple photographs and video footage. The video footage has been found to be helpful in explaining the complex geometry involved in some of the connection types.

2.5 Fastening and joining

The fastening-and-joining chapter of EDICS offers the user an extensive study of most devices and methods of fastening and joining parts together. Because one of the most important characteristics of a fastening or joining method is to inhibit separation of two materials, this chapter also introduces several possible failure modes that these methods commonly undergo. The list of fasteners presented in this chapter is quite extensive; screws, bolts, nuts, pins, studs, and rivets, as well as the nomenclature that accompanies each device, are all discussed at length. More permanent methods of joining materials together, such as soldering, brazing, and welding are also explained. As always, in the examples section of this chapter, photographs and video clips are used to further explain each fastening and joining method and how it is employed. An introduction to material properties such as yield strength, hardness, and Poisson's ratio is also introduced in this section, since the many fasteners available to a design engineer are made from a large number of distinct materials.

2.6 Transmissions

This chapter introduces the subject of transmission of energy over a distance. This not only includes mechanical energy transmission in the form of common elements such as gears and chains, but also electrical energy transmission in the form of electric grids and generators. In the physics section of this chapter, the basic nomenclature and processes involved in transmission of power using gears, chains, and belts is discussed, along with a description of the many different types of these elements. The various geometries of the transmission elements are also shown, allowing the user to correctly associate common features between elements.

Both the types and examples sections of this chapter are quite extensive, offering insight into many automotive and electrical elements. Clutches, cams, and splines are introduced, and their application into automotive design and operation are explained through text, photos, and video examples. Electrical transmission devices, such as remote electrical systems and generators, are introduced but discussed only briefly due to the complexities and large scale associated with the devices.

2.7 Material selection

The goal of the material-selection chapter of EDICS is to introduce the user to the many categories of materials that are available for engineering design and their behaviors in design situations. It is not, however, intended to be a detailed index of materials to be referenced when making design decisions. The categories of materials that are discussed are: ferrous materials, non-ferrous materials, alloys, polymers, wood, ceramics, and composites. It is clear that these categories do not encompass all known materials, but they do cover a very wide range of materials that are commonly used for mechanical design.

In the physics and design-specifications sections of this chapter, various material properties are introduced, including ultimate tensile strength, toughness, and fatigue limit. Fatigue, in particular, is discussed at length, since it is the most common cause for failure in most design situations. The good-practice section of this chapter also highlights some important information to consider when designing with different engineering materials. Some common safety factors for different industries and advice on avoiding stress concentrations are provided, and several surface-treatment methods for increasing fatigue performance are discussed.

The seven chapters of EDICS are filled with helpful information and entertaining activities for the curious engineer or designer. Each chapter offers insight into an important, and often extremely practical, area of engineering design which can motivate students to become better-rounded and more intelligent engineers.

Chapter 3

An Analysis of the EDICS Material

EDICS is an exciting program that holds enormous potential for informing eager young minds and stimulating engineering curiosity. It is not, however, a flawless or all-encompassing program. Along with its many benefits for the young engineer, it does portray some shortcomings. Those benefits and shortcomings will be discussed in the following chapter of this thesis.

3.1 Benefits of EDICS

There has been a great deal of research done to show that multimedia-based teaching programs are helpful in conveying subject matter to students. They offer students a chance to take control over their learning and develop their skills at a self-determined rate. For the past few decades, computers have become integral tools used in nearly all engineering curricula due to their calculation and presentation abilities. Like computers, media-based instruction methods have the ability to dramatically increase efficiency in the classroom and capture students' attention.

One of the most substantial benefits of EDICS is its ability to convey meaningful information about many aspects of engineering design in a neatly-packaged program that takes relatively little time to navigate. The interface of the program is easy to learn, and the large, clear buttons simplify the screen, allowing the user to explore the screens quickly and easily. Another practical benefit of EDICS is its inclusion and discussion of several components and processes that make use of common engineering skills such as math, chemistry, and physics. Through this, EDICS does its part to answer the engineering student's everlasting question: "When will I ever use this?"

A third important benefit of the program is its allowance for students to progress at a personalized pace. Oftentimes, fast-paced and challenging engineering courses can cause a lack of self-confidence or even poor overall academic performance for students [8]. The interactive menus and clear, concise manner in which EDICS introduces concepts teaches students efficiently and effectively, while still allowing review and reflection at any time.

3.2 Shortcomings of EDICS

Besides the many benefits provided by EDICS, there are some inherent shortcomings. First, EDICS is a program created to help increase inexperienced engineering students' abilities and confidence level in mechanical design, particularly those who have not had practical experience in engineering hardware. It is not intended to take the place of a formal engineering education or to be a substitute for hardware experience, nor is it intended to make experts of those who study the various chapters. It is simply an introduction to different areas of mechanical components and design.

Second, to provide an adequate level of understanding of the subjects addressed in EDICS, it is obvious that the program must be paired with more traditional teaching methods such as lectures, textbook readings, practical work in labs or shops, and written assignments. There is an intended lack of quantitative material in EDICS due to the fact that, were it included, the size of the program would inflate enormously and its audience would be reduced because of the program's increase in complexity. Another reason quantitative material is not included in EDICS is the obvious benefit of physically writing, computing, and solving engineering problems by hand. This allows students to develop good organizational and problem-solving skills, which may be difficult to do when simply interacting with a computer program.

Third, the lack of quantitative, overall assessments within EDICS make it difficult for students to estimate their progress in each subject area. The personalized feedback students receive on graded assignments such as homework, quizzes, and tests helps the student identify his or her weaknesses and improve upon them. This feedback is absent in many computer programs, including EDICS (although "self-tests" are occasionally incorporated), and although the users benefit from the interaction and content of the software, they do not walk away with a concrete sense of accomplishment or success.

The many benefits and shortcomings of EDICS discussed in this chapter are some of the more evident and important aspects of the program. To reinforce some of these benefits, and perhaps identify or improve upon some of the shortcomings, a quantitative evaluation of EDICS is needed. That evaluation is discussed in the next chapter of this thesis.

Chapter 4

Testing the Effectiveness of EDICS

In mid-late 2005, several students were asked to participate in a paid examination to test the effectiveness of EDICS in a classroom-style environment. It is fairly obvious that the use of multimedia-based aids has considerable educational benefits. A significant amount of research has been conducted in this area with a wide variety of teaching tools, although most research has centered on tools with a somewhat narrow scope. For example, in 1996 Melissa Regan and Sheri Sheppard, both of Stanford University, showed that providing multimedia-based materials to students when disassembling a bicycle for a class exercise "played a positive role in assisting learning" for a motivated group [20]. Also in 1996, Robert A. Chin and Amy R. Frank of East Carolina University played an important role in integrating the university-wide Multimedia Instruction Initiative, which provides various media-based resources to assist faculty members in their respective curricula [3]. The current evaluation of EDICS was conducted to determine whether EDICS held any significant, measurable benefits when compared to traditional textbook-based learning. This chapter will describe the testing strategy, the results of the examinations, and will discuss the overall results of the evaluation.

4.1 Testing strategy

In 1990, David Crismond, a graduate student at both the Harvard Graduate School of Education (HGSE) and MIT, conducted an evaluation of the initial release of EDICS that consisted of comparing a paper-based version of the software with the fully-functional computer-based version. The evaluation found that, among other things, novices benefited from using EDICS significantly more than their more experienced counterparts, and that there was no significant difference in scores between students who used the paper-based version of the material and those who used the computer-based version [4,5].

The latter observation was not unexpected, since the paper-based version was simply a printout of the computer screens from the media-based version. In an attempt to conduct a fair evaluation, Crismond did not test on any facet of EDICS that was treated only in the animations and videos. Thus, in some ways, he was actually unfair to EDICS since these are the areas that seem to teach students most effectively. Also, two chapters in EDICS – the mounting of rotors and levers to shafts and the connections between cylinders – are not explicitly covered in most popular textbooks, and thus were not tested by Crismond.

A more realistic criticism of the program was desired for the current evaluation of EDICS. Thus, EDICS was compared with paper-based material from an engineering textbook and a pre-existing booklet that covered much of the same material. Selected excerpts from the paper-based materials would be read by half of the test subjects, in this case undergraduate students at MIT, for a given period of time, and the other half would study EDICS for the same time period. After studying a given topic, the students would be given a short written exam to test their newfound knowledge. The test questions were explicitly answered in both EDICS and the paper-based materials, and the topics were covered by both tools in a clear and concise manner to ensure an unbiased evaluation of EDICS. The test materials used for this evaluation may be found in Appendix A attached to this thesis.

Three areas of EDICS were selected for testing: transmissions, fastening and joining, and drawing and drafting. These areas were selected for their range in media-based content and approach, as well as for their chronological separation as additions to the EDICS program. These chapters were also found to be covered by many engineering textbooks.

Before participating in the evaluation, the students completed a survey to determine their level of experience in selected areas of engineering design and mechanical components. This survey asked the students their gender, age, and undergraduate year. It also asked the students to rank their confidence level in the different subject areas they were about to study from one to five, with a rating of one representing the least amount of confidence, and a rating of five representing a great deal of comfort and confidence in the topic. This survey can be found in Appendix B.

For the transmissions portion of this evaluation, the students were asked to study the different materials for one hour. After this study period, the students were given fifteen minutes to complete a fifteen-question, multiple-choice quiz covering the various topics they had reviewed. These same time periods were allowed in the fastening-and-joining portion. In the drawing-and-drafting portion of this evaluation, however, the students were given only forty-five minutes to review the material, since the length of the chapter in both EDICS and the booklet were significantly shorter than the other two. The time periods given to the students were sufficient for them to conduct a thorough initial perusal of all materials from beginning to end, with the personal pace of each student determining whether a review of the material would be possible.

4.1.1 Recruitment of students

Recruiting students to test EDICS proved to be somewhat difficult. Since the total time required to complete the examinations was slightly over three hours, it is not surprising that many students declined the invitation to participate. Those who did, however, found EDICS to be informative, useful, and entertaining, especially compared to the excerpts from the paper-based materials. The students, who were comprised of undergraduates in the mechanical-engineering and aeronautics-and-astronautics departments at MIT, were offered $25 to take part in the study. Students in these courses of study were singled out due to the fact that the intended audience for EDICS is those who have a limited and inexperienced background in mechanical components and design, which are important areas of study in these curricula.

Ten students, eight females and two males, were tested in all, whose class rank ranged from freshman to junior. The class rank of all the students at the time of examination can be found below in Figure 3. Students with a higher level of understanding concerning engineering components and methods, such as seniors and graduate students, were avoided for the purpose of this testing since the results of their examinations may have skewed the results.

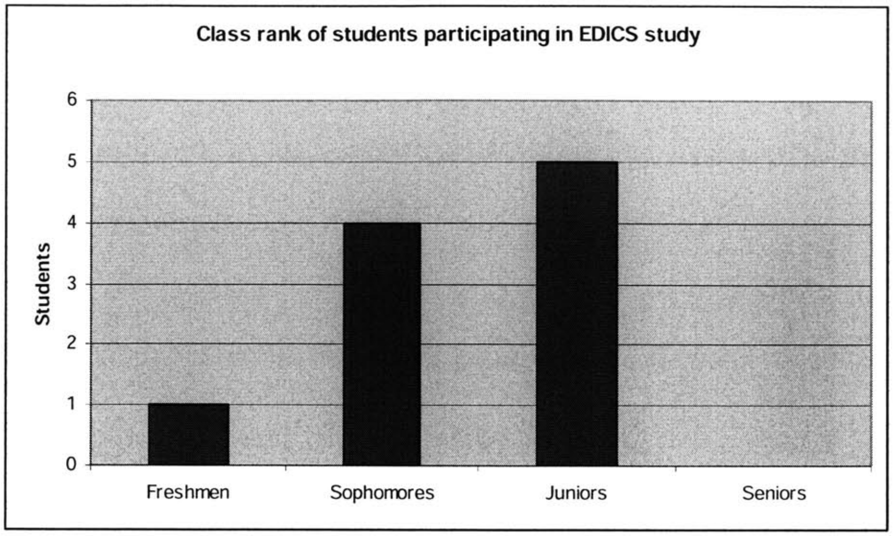

Figure 3: Class rank of surveyed students

4.1.2 Selection of appropriate comparative materials

To properly test the effectiveness of EDICS on engineering students in a realistic environment, a popular engineering design textbook was chosen for its comprehensiveness, detail, and similar subject matter. The text, *Fundamentals of Machine Component Design* by Robert C. Juvinall and Kurt M. Marshek [13], is used extensively in the U.S. at several major universities, and can also be found in use outside of the U.S. in countries such as Canada, Britain, China, and Australia. The textbook is excellent for its coverage of a wide range of material, while simultaneously keeping the reader interested with various anecdotes and examples.

Selecting a single text with which to compare all the material in EDICS is a difficult, if not impossible, task. The scope of EDICS is very broad, and most textbooks do not cover all the material offered in the program. For example, the more practical chapters of EDICS, such as mounting shafts to rotors and connections between cylinders, are simply not found in most engineering textbooks. These chapters provide necessary and applicable information of which all engineering students should be aware, and thus it is quite surprising that many engineering design textbooks do not contain it. There are some textbooks, however, that cover other chapters in EDICS quite well. The above text was chosen due to its similarity to EDICS in two of the subjects that were tested. Nearly all of the material from the fastening-and-joining chapter and the transmissions chapter in EDICS is provided in great detail by Juvinall and Marshall, and thus it served as a satisfactory comparative text.

The paper-based material for the examination concerning engineering drawing and drafting came from an existing booklet written by David Wilson, Ernesto Blanco, and two MIT undergraduate research assistants [2]. This material was chosen due to the fact that the Juvinall and Marshek text does not offer sufficient coverage of this subject area. The topics covered in the booklet were derived from the drawing-and-drafting chapter of EDICS, therefore much of the text is quite similar.

With these two paper-based study aides selected, the testing procedure described above was completed. The results of the examinations, and a discussion of their implications, conclude this chapter.

4.2 Test results

The survey completed by the students prior to participating in the study yielded some positive, yet interesting, results. The highest average confidence level in any of the topics tested was 2.7/5.0 in the subject of engineering drawing. This "high" level of confidence may be explained by the fact that engineering drawing is a subject studied at a relatively early stage in most engineering curricula, and thus the surveyed students all had some experience with it. The average confidence level (μ) and standard deviation (σ) in all subject areas can be seen below in Table 1.

Table 1: Student preliminary survey data

Topic	Comfort level	
	μ	σ
Transmission elements (gears, chains, belts, etc.)	1.8	1.0
Automotive elements (cams, clutches, brakes, etc.)	1.6	0.7
Threaded fasteners (i.e., screw/bolt terminology, uses, etc.)	2.1	1.6
Rivets, pins, and other non-threaded fasteners	2.1	1.4
Soldering and welding (different types and techniques)	2.3	1.2
Engineering drawing/drafting (views, dimensioning, etc.)	2.7	1.3
Drawing/drafting tolerances (techniques and principles)	2.1	1.1

From the results in Table 1, it can be said with some certainty that the students participating in this evaluation of EDICS were highly aware of their shortcomings in most of the subject areas they would study in the examinations. These data support the fact that this group of undergraduate students represents a portion of the target audience EDICS is intended to assist.

The results of the examinations on transmissions, fastening and joining, and drawing and drafting can be seen below in Figure 4. It is clear from the results that the students, in general, performed better on the examinations when studying EDICS rather than the paper-based material. It is also clear from the results that, in this study, students tended to gain more from EDICS as opposed to the paper-based materials when studying transmissions and fastening and joining as opposed to drawing and drafting. However, it stands to reason that the scores in the drawing-and-drafting examination should be roughly similar, since the EDICS material and the paper-based material in that subject contained essentially the same material and language. In fact, this result is consistent with the result found by Crismond in 1990 which showed that there was no significant difference in test scores between students that studied a previous version of EDICS and students that studied paper-based screenshots of the program [4].

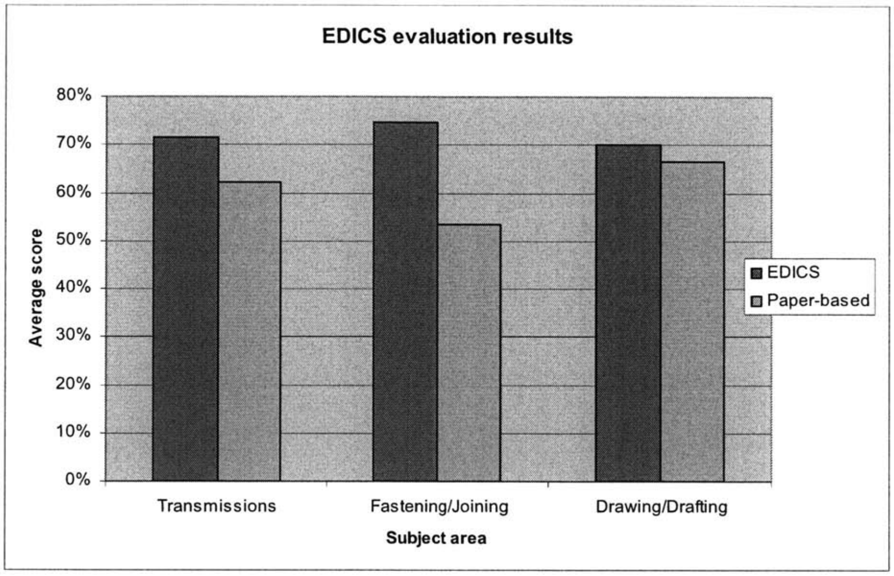

Figure 4: EDICS evaluation results

To further study the results the evaluation, a statistical analysis was conducted to determine whether the EDICS scores and the paper-based material scores were in fact significantly different, or if their difference was simply a chance occurrence. The tool that was used was a standard t-test, which is one of the most common statistical methods used to study experiments with relatively small sample sizes. The results of the t-test may be found below in Table 2. In this test, alpha (α) represents the chosen significance level. The significance level, or alpha level, states the percentage chance that one would observe statistically significant results even if there was none. In other words, it is the percentage that statistically significant results are observed by chance. An alpha level of

0.05 is the standard level chosen for most research. The degrees of freedom seen in the table below represent the number of examination scores that are free to vary in the statistical analysis. The degrees of freedom are calculated for the t-test by simply adding the number of persons in both groups and subtracting two. The two groups, in this case, are the students studying EDICS and the students studying the paper-based materials. Finally, t in Table 2 is the ratio of the difference between the group means to the variability of the individual groups.

Table 2: Results of statistical analysis of EDICS evaluation

	Transmissions	Fastening and joining	Drawing and drafting
Degrees of freedom	5	6	6
α	0.05	0.05	0.05
t	3.400	2.731	0.346

To complete the t-test, the values of t calculated in Table 2 were compared with the critical values of t for the given conditions, which can be found in any table of standard significance, or by simply creating a table of critical t-values in Microsoft Excel using the TINV function. The critical values of t for the transmissions, fastening and joining, and drawing and drafting subject areas were found to be 2.571, 2.447, and 2.447, respectively. Since the t-values found for the transmissions and fastening and joining subject areas exceed these values, it can be stated that the differences in scores between the students using EDICS and the students using paper-based materials to study these two areas were statistically significant. This outcome indicates that students not only enjoyed using the EDICS software, but they displayed a higher retention of the information they studied and had a clearer understanding of the material after interacting with the text, photos, and videos contained in the software. In the drawing-and-drafting examination, the t-value of 0.346 does not exceed the critical value of 2.447, and thus the scoring difference in this area is found to be not statistically significant. This conclusion does not imply that students did not benefit from using EDICS in this subject. It does indicate, however, that the contents of that particular chapter of EDICS and the contents of the paper-based material were equally effective in communicating information to the group of students.

4.3 Discussion

The results of this evaluation of EDICS show that the program is indeed a useful tool that can help to improve the quality of engineering education. The statistical analysis was a necessary task to prove that the positive results of using EDICS could not simply be a chance occurrence in this particular situation. It is critical for the success of programs such as EDICS that these unbiased evaluations take place at many stages in their development and implementation [16].

During testing, the students that participated in the study portrayed several noteworthy behaviors and study habits. First, students who combined their study of the EDICS or paper-based material with note-taking generally scored better on the examinations that followed. It has been widely observed for years that note-taking significantly improves students' retention skills. EDICS provides an ideal source for note-taking, since many of its screens contain short, summarized text blocks that can easily be written down by students. Second, the pace of the students participating in the study was widely varied. While some students carefully navigated through the content at a slow, determined rate, others skimmed through the material in a very short amount of time, then revisited portions in the remainder of the study period. For instance, several students would breeze through the EDICS material, only to find that there was a significant amount of study time remaining after they had finished. The students who displayed this behavior generally spent the remainder of their time reviewing the video examples found within the chapter or returning to the lengthier sections within the program to refresh their memories. A general trend observed during testing was that the students studying the EDICS material spent, on average, less time conducting an initial examination of the subject matter than the students studying the paper-based material. This trend leads to the conclusion that EDICS is more efficient than traditional paper-based materials at communicating information regarding transmissions, fastening and joining methods, and possibly drawing and drafting techniques and principles.

Chapter 5

Implementing EDICS into a Curriculum

The engineering education community has not yet implemented the widespread use of media-based engineering teaching tools in the area of mechanical design. However, there have been several examples of successfully employing media-based tools in areas of engineering ranging from dynamics to multimedia development [15].

It is not entirely feasible to base an entire course on EDICS alone. Textbooks are still extremely useful in teaching engineering design. Research has shown that students who study engineering design with the use of a textbook possess greater problem-solving and reasoning skills than students who attempt to solve design problems without consulting a text [1].

Perhaps the most widely-used pedagogical method for teaching engineering design is project-based learning, in which students participate in multidisciplinary projects to learn the design process and manufacturing and prototyping techniques [7]. The popularity of this instruction technique simplifies the process of introducing media-based software such as EDICS, since students participating in project-based learning must actively seek out sources of information to assist them in their projects. This chapter will examine various methods and positive and negative effects of implementing EDICS into an engineering curriculum.

5.1 EDICS as a Non-required Course Study Aid

The integration of EDICS into an engineering design course is a sensitive subject. Many engineering design faculty have proven methods they use to communicate concepts, ideas, and components to students, and are somewhat hesitant to incorporate a new technology into their syllabi. An implementation method that averts the possibility of interfering with the traditional instruction methods is to include EDICS in a course as a non-required study aid. Of course, simply including EDICS on the course syllabus is not enough to encourage most students to investigate it, so in-class reminders about the program and its coverage areas may be a good way to effectively supplement the standard course materials. One drawback to this implementation method is that students may not use EDICS because they see it as superfluous work and effort on their part. Although this possibility does exist, the motivated audience EDICS is intended to reach would still presumably seek out the program.

5.2 EDICS as a Required Course Supplement

Implementing EDICS as a required course supplement may be an effective method to introduce the program to young engineering students. Requiring students to interact with select portions of EDICS on a regular basis to supplement the material studied in the classroom would help ensure that all the students possess the same level of knowledge and understanding. For example, asking students to study a particular chapter of EDICS before beginning a related textbook chapter would reinforce the qualitative content found in the text with the practical examples and applications found in EDICS.

Short quizzes or homework assignments could accompany these EDICS tasks to provide the students with the proper motivation.

One fairly obvious caveat accompanying this introduction method is the possible boredom or frustration of students who are well-experienced in the EDICS subject areas. While this is a legitimate concern, it is no more disconcerting than the idea of such students becoming bored or frustrated with traditional textbook materials and assignments.

5.3 EDICS as a Stand-alone Instructional Tool

A third option for implementing EDICS into an educational environment is simply to distribute it to incoming or outgoing students in a particular field of study. Distributing EDICS during course registration or orientation would target all the students in a particular area, which would help spread EDICS throughout the school population. Also, since EDICS is available online as well as on a CD-ROM, a viable solution for distributing knowledge of the software would be dispensing flyers or sending emails to various groups of students directing them to the location of EDICS online. While this option does not actively encourage interested students to combine textbook material with the interactive, media-based material found in EDICS, it at least informs students of the existence of EDICS as a pool of knowledge to help them expand their knowledge of mechanical design and components.

Chapter 6

Future Work with EDICS

Although the current state of EDICS is more than sufficient to provide an inexperienced student with ample material to strengthen his or her abilities and confidence level, there are some general improvements that could be made to the program. This chapter will focus on some of those improvements, and how they might increase the effectiveness of EDICS.

6.1 Shared source code

The widespread sharing of the EDICS source code could help to significantly improve the program. Examples of software platforms that have successfully released their source code for public use and improvement are extensive. For instance, the Linux operating system, the Apache web server, and the Mozilla web browser are all open-source software [18]. These products have made tremendous progress since becoming freely available to programmers throughout the world, and their popularity and robustness can surely be attributed to the collaborative improvement process made possible by their openly-available source code.

Allowing the general public to have access to the EDICS source code may introduce both improvements and complications to the program. The improvements are obvious; EDICS would benefit greatly by having a more diverse and experienced set of authors provide a greater range of information to educate inexperienced and motivated students. The complications would arise, however, if many authors modified the EDICS code and were not entirely consistent with the mission and format of the program. Thus, it is essential that, if the EDICS source code is released for distribution, any future authors of additional EDICS material must keep in mind the cohesiveness of the program and its effectiveness through organization and consistency.

6.2 Expansion

The current state of EDICS covers a wide range of topics regarding mechanical components and engineering design, but there are still many areas in which the program could e expanded. The seven subject areas EDICS currently addresses are consistently problematic for young and inexperienced engineering students. To stay true to the theme of EDICS, additional subjects such as the design process, prototyping techniques, or design for manufacture and assembly (DFMA), all of which being relevant to mechanical design and often not well understood by inexperienced students, may be researched for inclusion within EDICS.

Along with the many chapters in EDICS covering mechanical components and their application in design situations, it may also be worth investigating more advanced topics that engineering students find problematic. Subjects such as statics, thermodynamics, and fluid mechanics often prove to be some of the most difficult in the mechanical-engineering curriculum. Although specialized multimedia teaching tools do exist for many of these advanced subjects [10,11,17], incorporating them into EDICS would allow the program to grow into a more encompassing teaching tool whose audience includes students with all levels of previous experience.

Conclusion

EDICS is a fun and useful teaching tool that covers a wide variety of topics and enhances the education of inexperienced engineering students. It is clear from the many students that have already benefited from EDICS that it is an enjoyable and helpful program that combines a sense of application and realism with the quantitative skills they have been taught in their classes. As Nobel Laureate Herbert Simon once said, "...for the computer to bring about a revolution in higher education, its introduction must be accompanied by improvements in our understanding of learning and teaching" [14]. Only by guiding students through their education with patience, understanding, and creativity can multimedia programs like EDICS hope to enable engineering students to succeed both in and out of the classroom.

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Appendix A: Test Materials

Transmissions Questions:

Please choose the most appropriate answer.

1. The difference between spur gears and worm gears is:
    a) Spur gears are found only on parallel shafts, while worm gears may be found on non-parallel shafts
    b) Spur gears may be used to "step up" and "step down" shaft angular velocity, while worm gears are generally only used for "step down" applications
    c) Interacting spur gears contain only straight-cut teeth, while interacting worm gears contain special helical-cut teeth
    d) All of the above
2. A gear ratio (a.k.a. angular velocity ratio) may be calculated as the ratio of:
    a) The pitch diameters of two interacting gears
    b) The diameters of two rotating shafts
    c) The forces transmitted between two interacting gears
    d) The power transmitted between two interacting gears
3. Gears are generally:
    a) Less expensive than chains and belts
    b) The same cost as chains and belts
    c) More expensive than chains and belts
    d) Less expensive than chains but more expensive than belts
4. Helical gears can be mounted on:
    a) Parallel shafts only
    b) Perpendicular shafts only
    c) Both parallel and perpendicular shafts
    d) Any shaft configuration
5. One of the main advantages of belts and chains over gears is that:
    a) More power can be transmitted by using belts and chains
    b) The transmission shafts may be spaced further apart when using belts and chains
    c) Both belts and chains provide more accurate speed ratios than gears
    d) They often last significantly longer than gears
6. With all conditions equal (such as shaft RPM, lubrication, and enclosures), the quietest form of transmission would be:
    a) Roller chain
    b) Spur gear
    c) Rack and pinion gears
    d) Inverted-tooth chain

7. Flat belts are often coated in rubber to aid in:
    a) Heat dissipation
    b) Increased friction
    c) Greater flexibility
    d) None of the above
8. In automotive clutches, with the clutch engaged, the clutch plate is pressed against which of the following:
    a) Flywheel
    b) Crankshaft
    c) Engine housing
    d) Connecting rod
9. Automobile disk brakes are generally powered:
    a) Pneumatically
    b) Mechanically
    c) Hydraulically
    d) None of the above
10. To "step-up" using a gear transmission means to:
    a) Increase the speed of the driven gear
    b) Increase the size of the driving gear
    c) Decrease the speed of the driven gear
    d) Decrease the size of the driven gear
11. Shock loadings (such as rapid start-up jerks) and vibrations are generally handled best by:
    a) Roller chains
    b) Flat belts
    c) Helical gears
    d) Inverted-tooth chains
12. Nearly all V-belts contain interior tension cords to aid in the strength and life of the belt.
    a) True
    b) False
13. In automobiles, the main clutch serves to disengage the engine from the:
    a) Alternator
    b) Starter
    c) Water pump
    d) Transmission

14. Toothed-belt drives differ from chain drives in that:
    a) They cost significantly less than chain drives
    b) They do not keep exact synchronization of the driving and driven shafts
    c) They don't need lubrication
    d) They have a much longer service life than chain drives
15. Disk clutches never operate lubricated, or "wet," since friction is essential for their operation:
    a) True
    b) False

Fastening / Joining Questions

Please choose the most appropriate answer.

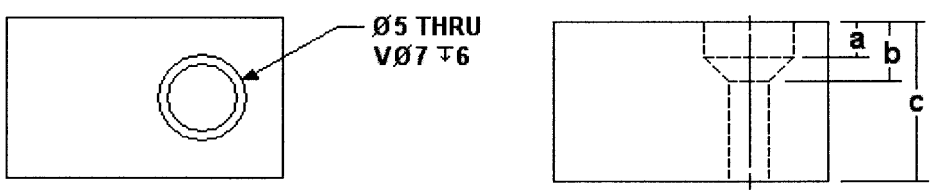
1. Using the Unified (inch series) terminology, the pitch of a screwed fastener refers to:
    a) The number of threads per inch
    b) The length of the fastener
    c) The shank diameter
    d) The distance between threads
2. Using the ISO (metric series) terminology, the pitch of a screwed fastener refers to:
    a) The number of threads per inch
    b) The length of the fastener
    c) The shank diameter
    d) The distance between threads
3. As the "grade" of a fastener increases, the strength and hardness of the fastener:
    a) Stay constant
    b) Decrease
    c) The hardness increases, but the yield strength decreases
    d) Increase
4. A stud differs from a bolt by all of the following features *except*:
    a) A stud is threaded on both ends
    b) Bolts have heads, while studs do not
    c) Bolts require a threaded hole, while studs do not
    d) Bolts are more common than studs in engineering design
5. Rivets offer the same attachment strength as a screw or bolt.
    a) True
    b) False
6. Of the choices below, which fastener would have the lowest price?
    a) Hex-head bolt
    b) Wood screw
    c) Double-ended stud
    d) Semi-tubular rivet
7. To join two pieces of sheet metal together with blind rivets, one must have access to both sides of the assembly.
    a) True
    b) False
8. The installation of castle nuts requires the use of which of the following fastening devices?
    a) Cotter pins
    b) Dowel pins
    c) Snap rings
    d) Continuous-thread studs

9. To prevent the loosening of a threaded fastener (such as a bolt) on an assembly, which device would most likely be used?
   a) Dowel pin
   b) Toothed lock washer
   c) Snap rings
   d) All of the above
10. The temperatures associated with brazing/soldering are:
   a) Lower than those associated with welding
   b) Higher than those associated with welding
   c) Similar to those associated with welding
   d) The temperatures associated with brazing/soldering can range from lower than to higher than those associated with welding
11. The filler material used when soldering (soft-soldering) has a melting temperature below 450°C (840°F), while the filler material used in brazing (hard-soldering) has a melting temperature above 450°C.
   a) True
   b) False
12. Gas-tungsten arc welding (GTAW) may also be called:
   a) Gas-metal arc welding (GMAW)
   b) Shielded-metal arc welding (SMAW)
   c) Tungsten-inert gas welding (TIG)
   d) All of the above
13. Which of the following groups of gases are normally associated with producing a shielding gas around the electric arc while welding?
   a) Carbon dioxide, helium, and argon
   b) Carbon monoxide, xenon, and nitrogen
   c) Sulfur dioxide, xenon, and radon
   d) None of the above
14. Rivets are sometimes installed with washers to distribute the mechanical load.
   a) True
   b) False
15. When brazing, the filler material is placed into the gap between the two materials to be joined by:
   a) gentle pressure from the operator
   b) capillary action
   c) a special tool that is used immediately following filler application
   d) gravity

Drawing/drafting Questions

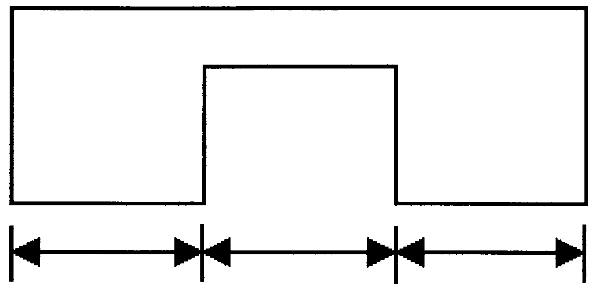
Please choose the most appropriate answer.

1. In a truly isometric drawing, where all lines are at their true (scale) length, at what angle are the lines in the width and depth planes?
    a) 20 degrees above horizontal
    b) 45 degrees above horizontal
    c) 30 degrees above horizontal
    d) 35 degrees above horizontal
2. In a standard orthographic drawing, how many views of an object are usually shown?
    a) Three
    b) Two
    c) One
    d) Four
3. In a cross-sectional view, diagonal lines (cross-hatches) represent:
    a) Material that has been cut by the viewing plane
    b) Material that lies behind the viewing plane
    c) Material that can be dimensioned more clearly in another view
    d) None of the above
4. Hidden (dotted) lines are not shown on cross-sectional drawings.
    a) True
    b) False
5. In the drawings below, the depth callout of 6 units refers to which distance?



    a) See drawing
    b) See drawing
    c) See drawing
    d) None of the above

6. The drawing below shows an example of which kind of dimensioning technique?

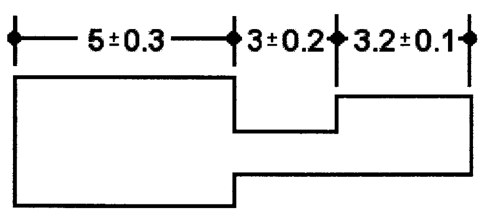


a) Baseline
b) Datum
c) Limit
d) Chain

7. A spotface is a simply a shallow version of a:
a) Countersink
b) Counterbore
c) Counterdrilled hole
d) None of the above

8. There are three forms of giving tolerances by direct dimensioning. Which one of the following techniques is not one of these forms?
a) Limit dimensioning
b) Bilateral tolerancing
c) Baseline tolerancing
d) Plus and minus tolerancing

9. In the simple (and not fully dimensioned) drawing below, the length of the part has a total variation of how many units?



a) 0.8
b) 0.6
c) 1.2
d) 0.4

10. The tolerancing technique used in the previous question (Question #9) is called:
a) Plus and minus tolerancing
b) Bilateral tolerancing
c) Baseline tolerancing
d) None of the above

11. When a dimension on a drawing is called out as a reference dimension (REF), that dimension is not necessary to fully describe the part.
    a) True
    b) False
12. The cutting planes on cross-sectional views must always be one-dimensional, straight lines.
    a) True
    b) False
13. An appropriate size (in millimeters) for an arrowhead on an engineering drawing would be:
    a) 3 mm long and 2 mm wide
    b) 4 mm long and 1 mm wide
    c) 2 mm long and 0.5 mm wide
    d) 6 mm long and 2 mm wide
14. Leaders may only be used to point out part dimensions, NOT to point out notes and comments.
    a) True
    b) False
15. If not explicitly called out on the drawing, the measurement system should be assumed as:
    a) Metric (mm)
    b) Unified (inches)
    c) Metric (cm)
    d) It should always be called out on the drawing

Transmissions Answers

1. d	9. c
2. a	10. a
3. c	11. b
4. c	12. a
5. b	13. d
6. d	14. c
7. b	15. b
8. a	

Fastening/joining answers:

1. a	9. b
2. d	10. a
3. d	11. a
4. c	12. c
5. b	13. a
6. d	14. b
7. b	15. b
8. a	

Drawing/drafting answers:

1. c	9. c
2. a	10. b
3. a	11. a
4. a	12. b
5. b	13. d
6. d	14. b
7. b	15. d
8. c	

Appendix B: Student Background Survey

Gender: Male / Female

Age: ________

Year at MIT: Freshman Sophomore Junior Senior

Imagine yourself about to take a quiz on the following topics. Based upon your previous education, please rate your confidence/comfort level in these topics.
(1 = least comfortable; 2 = somewhat comfortable; 3 = comfortable; 4 = very comfortable; 5 = most comfortable)

Topic	Comfort Level				
Transmission elements (gears, chains, belts, etc.)	1	2	3	4	5
Automotive elements (cams, clutches, brakes, etc.)	1	2	3	4	5
Threaded fasteners (i.e. screw/bolt terminology, uses, etc.)	1	2	3	4	5
Rivets, pins, and other non-threaded fasteners	1	2	3	4	5
Soldering and welding (different types and techniques)	1	2	3	4	5
Engineering drawing/drafting (views, dimensioning, etc.)	1	2	3	4	5
Drawing/drafting tolerances (techniques and principles)	1	2	3	4	5

Please list any specialized training or experience you may have with the topics above. (For example, internships with a gear or chain manufacturer, school projects where an above topic was thoroughly studied outside of class, participation in a club at MIT that deals with an above topic on a fairly consistent basis, etc.)

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