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ABSTRACT

This study focused primarily on two types of computer interfaces and the differences in academic performance that resulted from their use; it was secondarily designed to examine gender differences that may have existed before and after any change in interface. Much of the basic research in computer use was conducted with command line interface (CLI) based computers and their Video Display Terminal based relatives that use the keyboard as their primary and often only initial input device. Today, graphical interfaces (GUIs), with the mouse or light-pen as the primary interface device, are becoming the rule in computer use. Thus, the question arises whether research on learning completed with command line interfaces is transferable to the graphical interface situation. Any changes of interface could have significant effects on how users use and how easily they can learn to use computers. The change from CLI to GUI also encompasses a change from the more abstract representations of actions to a more concrete representation both in file manipulation and information preparation and presentation. The final grades of students enrolled in either of two introductory computer science classes were analyzed from the fall semester of 1987 through the fall semester of 1990. During this time period, instruction was changed from CLI-based to GUI-based instruction. The findings do not indicate any gender differences based on interface and do not indicate that there is any statistically significant difference between the interfaces used. The appendix provides a historical analysis of computer interfaces. (30 references) (DB)

Gender differences between graphical user interfaces and command line interfaces in computer instruction

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Running head:

Gender differences in using computer interfaces

Abstract

Much of the basic research in computer science instruction was conducted during the era of command line interface (CLI) based computers and their Video Display Terminal based relatives who use the keyboard as their primary and often only initial input device. Today, graphical interfaces (GUIs), with the mouse or light-pen as the primary interface device, seemingly are poised to take over all classroom computer installations in the near future.

There is an important question that must be raised with this transition from command line based interfaces to graphical user interfaces: Is the research on learning completed with command line interface based computers transferable to graphical user interface based computer situations? The change in the primary input device (from keyboard to mouse) may be a newly confounding factor for past research conclusions.

The user interface is the area of the computer that is probqbly most necessary for a user to understand. Its paradigms and theories are usually implemented in many programs used on the machine making it an integral part of using any computer. Any changes of interface could have significant effects on how users use and how easily they can learn to use a computer. The change from command line based to graphical based interface also encomapses a change from the more abstract representations of actions to a more concrete representation both in file manipulation and information preparation and presentation.

With the conventional though possibly not proven conventions of gender differences between abstract representation and concrete representation abilities and comprehension, the research was designed also to examine gender differences that may have existed before and after any change in interface.

The final grades of students using both CLI and GUI interfaces for introductory computer science class work and comparing the two, both overall and by gender, were analysed for this study. The findings do not indicate any gender differences based on interface and do not indictate that there is any statistically significant difference between the interface used. One part of the findings that is particularly interesting was that students who change from CLI to GUI devices between their introductory classes in computer science received grades in the second class that were closer to their grades in the first class than students who did not change interface.

Today, graphical user interfaces* (the working definitions for all starred terms are provided in Appendix 2), also called GUIs, are becoming the foundation of much of computing*. In the past, many studies have been conducted to measure how quickly users* can be taught computing. Most of these studies have focused on VM/VMS, Unix and MS-DOS based computers* or their predecessors which use a command line interface* (CLI). The problem for future researchers is whether the change in interface*, from CLI to GUI that is occuring in many computer instalations, confounds the findings of past research done on exclusively CLI machines.

The user interface is the area of the computer which is probobly most necessary for a user to understand. Its paradigms and theories are put in many programs used on the machine making it an integral part of using any computer. Any changes of interface could have a significant effect on how users use and how easily they can learn to use a computer. The change from command line based to graphical based interface also encomapses a change from the more abstract representations of actions to a more concrete representation both in file manipulation and information preparation adn presentation.

The unproven, conventional understanding of males' and females' methods of understanding the world around them, indicates that the genders are not equal in their ability to use abstract versus concrete models and representations of materials and ideas. This gender difference between abstract representation and concrete representation abilities and comprehension may show itself in the differences between GUI and CLI based instruction.

Past research has been done primarily in CLI based environments. The primary factor that explains this tilt toward CLIs in research is their prevalence throughout the academic community from the 1960s through the 1980s (For a detailed history of interfaces see Appendix 1). The prevalence of CLIs seems to have been strong enough that many researchers do not note the brand, model or operating system of computer used in their study and often do not name the software used within the study beyond its general category such as word processing or accounting. From the literature review that follows, it appears that interface has seldom been viewed as an important variable in computing.

One potential confound for past research is that many studies that do deal with GUI technology have been published by or sponsored by interested parties, such as the manufacturers of GUIs. The fact that interested parties are the organizations studying the phenomenon is not rare in research, and good studies are conducted by interested parties. Still, these findings must be questioned until independent research confirms these findings.

The problem of interested parties sponsoring research shows more clearly in an example. Durance and Fenton's 1986 article published in Learning tomorrow: Journal for the Apple education advisory council, a publication of Apple Computer, shows where the possibility for interested parties to bias research could occur. In that journal, Durance and Fenton explain the choice of computer to be the center of their study with the following statement: "The Macintosh was chosen to support the course because of its consistent and easy-to-use graphical interface. And because of the abundance of good Macintosh software." (p. 5)

No further explanation for this decision is provided in Durance and Fenton's article. Three questionable claims are contained in their explanation: 1. The statement's claim of good Macintosh software is abundant can not be contradicted, but since their study discusses the educational use of computers and networks. It is not the abundance or quality of general Macintosh software that must be considered but the amount of Macintosh-based, educational software that is important. This factor makes this claim possibly the most questionable claim of the sentence. When it is noted that some schools have resisted the purchase of Macintosh computers because so much more educational software has been available for the IBM-PC and Apple II lines of computers the claim becomes more questionable; 2. Durance and Fenton also claim that the consistent interface was a factor in their decision; however, most software companies that issue a series of related programs (e.g., the PFS series of programs on the Apple II and the IBM series of computers) provide users with a consistent interface. Most computers when studied as a whole have a consistent interface in may of their programs, though not to the high level of consistency that Apple has set as a standard on the Macintosh and other companies have made possible through their program lines. 3. "Easy to use" is an unproven and undefined factor for Durance and Fenton's study of the Macintosh. At least two IBM users who this researcher has interviewed find the rules of GUI intimidating because they are so different from their "easy to use" command line interface.

The choice of Macintosh computers is not supported as the sole logical conclusion given the cited factors. Apple II and IBM-PC computers could meet the same criteria. The fact that their article was titled: "The network advantage in education for the Apple Macintosh," and that the discussion of the ease of use of Macintosh networking is made without discussing similar features for IBM-PC or Apple II computers, indicates a possible bias toward the Macintosh over other computer installations and configurations that could have similar results.

Still, Durance and Fenton's conclusion that Macintosh computers are good computers to use in a network can not be disproven. Unfortunately their unporven assumptions that lead them to this conclusion limit the applicability of their other conclusions. The lack of side-by-side comparison with other, similar computers and the fact that the study was published in a journal owned by an interested party makes Durance and Fenton (1986) an example of where good research was done, but further research is needed to expand upon the exact meaning of their findings and conclusions.

A second example, from a book published by a pseudo-governmental research organization, shows some other limitations of research done by or using interested party's support. Europe's ESPRIT committee, studying information systems (Christie, 1989), also indicates that GUI systems have advantages for usability, and makes many interesting points about the differences between GUI and CLI interfaces. Unfortunately, the ESPRIT study never looks at GUI and CLI technology side by side in common activities performed with computers. The committee was made up of people from organizations interested in information systems technology including Xerox, Apple Computer and Wang - three companies that had made large investments in GUI systems. IBM, a traditional advocate of CLI and GUI equivalence, was not represented at that conference.

Now that some limitations of past GUI research has been discussed; a more thourough review of past research can begin as well as a discussion of the design for this study.

Literature Review.

The effect of possible differences in computer interfaces has not been widely studied or reported. Studies of gender factors in using a computer are much more reported in published literature. This literature on gender differences that does not take interface into account, will be considered in the interpretation of the effect of interface on computer use since there is a conventional wisdom that indicates the interface's differences may be tied to gender differences.

Gattiker (1989), using apparently CLI based computers (assumed from the software he named), found that gender differences are not of great magnitude and that any differences can be offset by training and instruction. Gattiker (p. 26) cites Campbell, Dunette, Lawler and Weick (1970) and Hinrichs (1976) as showing that there is disparity between males and females in measured computer ability at entry into computer classes. Gattiker did not find similar differences at the exit from computer classes. In Gattiker's references to Campbell, et al. (1970) and Hinrichs (1976) males' poorer keyboarding skills and females' gender–role stereotyping are named as probably the main disadvantage that limits the ability for each to learn computing.

Collis, Kieren and Kass (1988) used a manifold model to quantify paths connecting the effects of various factors that determine high-school students' use of computers. The factors identified in that study (pp. 25-27) are:

Parent's educational level

Home computer presence

Academic achievement

Stereotypes

Having taken a computer course

Being computer competent

Perceived value of computers

Self confidence

Liking of computers

Frequency of school use of computers

According to the study, these ten factors, connected by 45 paths, explained 97.9% of the variability in male usage of computers and 97.6% of the variability of female usage of computers. An analysis using only 25 paths accounted for 93.9% and 91.4% of the variability in males and females computer usage, respectively. These ten factors which serve as predictors of usage are important to note. Though the Collis, et al. (1988) study was conducted among high school students, similar factors may affect college student's computer usage.

Collis, et al. (1988) also reports that previous studies (specifically Collis, 1987; Ellis & Sayer, 1986; and Lockheed & Fracht, 1984) found that stereotyping is a strong factor in determining computer usage by gender, and that, "sex differences in such [computer usage stereotypes held by adolescents] can arise and be personally enframing, particularly for females." (Collis, 1988, p. 15)

Arnez and Lee (1989) reported their finding that "the idea of computer science being a male domain is prevalent among females in introductory classes but [is] much lessened in intermediate classes." (Arnez and Lee, 1989, p. 17) and cites Schubert (1986) as finding that "computer study may be exacerbating [a well defined pattern of inequality] by reinforcing existing gender inequities rather than encouraging educational equity." (Arnez and Lee, 1989, p. 6) Restated, Schubert found that because there are presently few females in computer classes, fewer females will take those classes and this disparity in the number of males and females in the field of computing will continue to increase unless some intervention occurs.

Arnez and Lee (1989) also cited several studies whose findings will be addressed as presenting potentially confounding factors to consider in this study. 1. Anderson, et al. (1984) and Lockheed, et al. (1984) found females had fewer chances to use computer aided instruction than males. 2. McCain (1983) found that females take more introductory than advanced computer science courses. 3. Loyd and Gressard (1984) found that males and females have similar attitudes toward computers in terms of computer anxiety, confidence and computer liking. 4. Mandinach & Fischer (1985) found that once in a computer science course male and female scores for computer ability become more equitable.

Question(s) to be studied.

This study is primarily designed to examine the applicability of CLI learning research when applied to GUIs. This study was secondarily designed to examine gender differences that may have existed before and after any change in interface as well as overall differences between CLI and GUIs that may confound past, present and future research that does not take possible interface differences into consideration.

The final grades of males and females being instructed upon the same material in each computing environment as well as for students who change interface during their instruction were statistically analysed for changed coinciding with interface changes. It was theorized that significant differences in the usability of the interface, if they exist, would be measurable thorugh such a study.

The primary question for this study is whether there is a measurable difference between people learning computing using GUI or CLI as their primary instructional paradigm. To move closer to an answer to the above question, three secondary related questions were studied:

1. Do the final grades of students using GUI versus CLI technology differ for similar instruction?

2. Do the average final grades of females or males in GUI centered classes differ from the average final grades of same-gendered students in CLI centered classes?

3. Does changing from first CLI to GUI centered instruction appear to affect the final grades of the involved students?

Data Collection.

The data used to study the three research questions were gained from the records of the Office of the Registrar of Trinity University, San Antonio, Texas. The resistrar provided copies of the final grade sheets for Computer Science I and II with the gender of each class participant indicated and based on their student records. The final grade sheets were submitted to the Office of the Registrar by each class section's instructor at the end of each semester. The grades were provided in alphabetic form (i.e., A, B, C, D, F) with plus or minus signs for high or low grades in each letter range.

CLI based instruction was used at Trinity University for their Computer Science I and Computer Science II classes (CSCI 311, and CSCI 312 respectively) before the fall semester of 1988. Beginning with the Fall Semester of 1988, and for all semesters since then, GUI based instruction has been used.

By analyzing and comparing the final grades of students in CSCI 311 and 312, before and after the change of interface, answers to the questions to be studied were obtained.

Method for Question 1.

The population for this study is all students receiving final grades in Trinity University's CSCI 311 and 312 from the Fall semester of 1987 through the Fall semester of 1990. This period was determined because in the fall of

1987 a new Computer Science curriculum was installed and thus comparisons to classes before that time would be limited due to the different subject matter studied. The spring semester of 1988 was the first time CSCI 312 was offered in its present form. It was not offered in the fall of 1987 because it was intended to continue the subject matter studied in CSCI 311 and no students had completed that course (CSCI 311) before that time.

The data for this study, as supplied by the Trinity University, Office of the Registrar, are based on a scale of points in the following order from worst to best performance: F, D, D+, C-, C, C+, B-, B, B+, A-, A. These letter grades we.e quantified by mapping them to the numbers used in a standard 4 point scale of grades: A is 4.00. A- is 3.66. B+ is 3.33. B is 3.00. C+ is 2.66. C is 2.00. C- is 2.33. D+ is 1.66. D is 1.00. F is 0.00. This is the same grading scale that Trinity University uses in calculating GPA for its students. Trinity University does not use A+ or D- as final class grades.

Insert Table 1 about here.

Students who did not complete the course, and thus did not receive a final grade, were not included in this study. Students whose work was incomplete at the end of the course term and that had not been completed when the data was collected were also not included in this study.

Question 1. data analysis and discussion.

The final grades of students in CSCI 311 and 312 before the interface change from CLI to GUI have a mean of 2.790 with a standard deviation of 1.179. The mean grade for all students taking CSCI 311 and CSCI 312 after the transition from CLI to GUI interface was 2.775 with a standard deviation of 1.178. The mean decreased only 0.015 across the change of interface.

Inse t Table 2 about here.

When the above data is subjected to a z-value analysis, which is designed to measure diferences between sampled populations, the above data yields a z-value of 0.013. This indicates that any differences between the groups are statistically insignificant at virtually any level of significance and indicate that this study failed to detect a significant difference in the final grades of the population that can be tied to the interface change.

Method for Question 2.

Methods for question 2 are identical with those listed in the methods for question 1.

Question 2, data analysis and discussion.

When the mean grade of only males was found for the period before the interface change, the result was 2.935 with a standard deviation of 1.254. For females during this same period the mean grade was 3.042 with a standard deviation of 0.884. The female mean is thus 0.128 higher than the males' mean average final grade.

The mean grades of students taking CSCI 311 and CSCI 312 after the transition from CLI to GUI interface were: 2.801 with a standard deviation of 1.157 for males; and 2.696 with a standard deviation of 1.232 for females. The female mean grade is thus 0.105 lower than the male average.

One remarkable feature of the above means is the 0.349 decrease in females mean grades across the interface change while the mean grade of males increased 0.099. When the above data is subjected to ANOVA, n=182 and F=0.532. Since the critical $F(.05)_{(3,200)}$ value is 2.650 this indicates that there is no statistically significant interaction between the CLI, GUI, male, female groups in this question.

Though the disproportionate change in grades for males and females which at-first may look impressive, there is no evidence to support that this numerical difference is anything more than a matural occurance of chance. Since a t or normal distribution of grades has been assumed for the simplicity and elegance of analysis there is the possibility that the grades do not follow normal or t distributions and are actually statistically significant, which would support there being an affirmitive answer to question 2. The researcher made no attempt to study this possibility.

<u>Method for Question 3.</u>

The population is all students receiving final grades in Trinity University's CSCI 311, and 312 during the period from the Fall semester of 1987 through the Fall semester of 1990. This is a shorter period of study than for Questions 1 and 2. Students are not required to take CSCI 312 the next semester after their completeion of CSCI 311. With the above defined period all students who took CSCI 311 before the interface change and CSCI 312 after the interface change are included. The period also provides data for at least one class-full of people who took CSCI 311 and 312 before the interface change and one class-full of people who took CSCI 311 and 312 after the interface change.

The grades were analysed to find how much of a change there was between each student's CSCI 311 and 312 grade. The difference between grades for CSCI 311 and 312 were measured using the 4 point scale described under the methods for questions 1 and 2.

Pearson's Rho is designed to analyze differences and covariance such as these and was used here to examine the covariance of the grades. Additionally a rough anaylsis of trends was performed on the data that was used to interpret further the results of the Pearson's Rho analysis.

Question 3. Data analysis and discussion.

The analysis showed that of the students who used CLI based instruction in both CSCI 311 and 312, 25% kept the same grade in their second class, while under GUI based instruction slightly under 40% showed no grade change. Most average final grades decreased for all groups of students. This decrease is presumably due to higher scoring students from CSCI 311 being graded with the same grade distribution as in their previous class though many lower performing students did not take CSCI 312.

Insert Table 3 about here.

Of the students who used CLI in CSCI 311 and GUI in CSCI 312, 50% (6 out of 12) had the same grade in both classes. This figure is higher than for the students who kept the same interface, indicating that the interface change lead to fewer final grades changing than using the same interface in both CSCI 311 and 312 for the population studied.

If instead of only studying the students with no grade change, all grades whose second semester grade fall within one standard deviation are considered to have had an "unchanged" grade by statistical laws; then the stability of the grade in 311 compared with the grade in 312 is as follows: for CLI in both classes, 64.2% had an "unchanged" grade; for GUI in both classes, 60.6% had an "unchanged" grade; and 91.7% of those students who changed interfaces had an "unchanged" grade. Even with this wider region of change viewed of insignificant it is interesting that the students who experienced a change in interface had grades in their CSCI 312 closer to their CSCI 311 grades.

When the correlation between a student's grades in CSCI 311 and CSCI 312 is evaluated using the Pearson's Rho, raw scores formula some interesting factors appear. Students who used CLI in both classes, during the period studied, had a r value of 0.245, while students who took both classes after the interface change had a r value of 0.618. For students who took CSCI 311 before the interface change and CSCI 312 after the change, r was 0.656. Thus, students who keep with the same instructional interface for both classes show less grade correlation than those who changed interfaces.

These results suggest that the answer to question 3, "Does changing from CLI to GUI centered instruction appear to affect the final grades of the involved students?" is yes. The change in interface appears to make a student's final grade in their next course change less than if the same interface is used for both classes studied.

This is an interesting finding and quite unexpected. Unfortunately the statistical significance of this result is dubious. While the r value is highest for those who changed interfaces; it is still only on the marginal of indicating that the grade a student receives in CSCI 311 is correlated with their grade in CSCI 312. The r-value for those who changed interface is also notably close to those who used GUI instruction only.

This proximity may indicate that the professors started using curved grades for their classes about the same time as the interface change. Another explanation for this result is that the grades were not curved and that the professors found tests that provided the desired grade results about the time of the interface change and continued to use them after the interface change.

Discussion of Limitations.

Since one standard deviation for the data could amount to half the range of the data set, that makes any conclusive and statistically significant findings difficult if not impossible to achieve. Said another way for a result to be significant it would have to be outside the range of the data. Non-parametric analysis may be necessary for a proper analysis of the data supplied and other

GPA based analysis. Future researchers should be wary of using GPA based data in cases such as this where the grade distribution is so flat or skew and may not follow the statistical assumptions of normal or t distributions.

Though the results of this study are statistically insignificant there are some interesting indications in the data, the drop in female average grades after the interface change remains an unexplained phenomenon of the data. The anomalous, and thus interesting, part of the data appears more to be the question of why the females in the sample had a higher average than males during the period they were using CLI centered instruction.

Discussion based on the Literature Review.

The literature review indicates that equity for males and female computing ability scores once instruction is under-way is to be expected under CLI conditions. This equity of final grades for the period after the interface change is quite apparent. For the period both before and after the interface change, that hypothesis is also supported.

While this study did not explore the background of the students or attitudes toward computer use, certain generalities however can be drawn by knowing related traits of the population the students came from. About the same time as the start of this study's period Trinity University began an agressive recruitment program for the best students in the country. This when taken with Collis, et al. (1988) may provide an explanation for some of the slight variations and trends found in this study.

For both questions 1 and 2, above, it is important to note some assumptions that have been made for this research. If it is assumed that the traits of the classes over the period studied are essentially the same and that there was not gender discrimination by the courses' graders or professors or other uncontrolled factors; then this finding indicates that graphical user interfaces are not as easy to learn or use for females when compared to males.

The literature review also indicated that any gender differences that may be present at the entry into computer courses quickly disappears; and that the factors determining the performance of females and males in computer science classes are similar (Gattiker, 1988; Campbell, et al., 1970; Collis, et al., 1988 and Mandinach & Fischer, 1985). There is not evidence in this study to refute any of those study's conclusions; and some circumstantial evidence supports those findings in the GUI environment.

No evidence was found to support possible sex-role stereotyping in the studied population. Yet, it must be noted that there is a strong disparity between the number of females and males who received final grades in the studied classes. This evidence tends to support the research findings of Anderson, et al. (1984) and McCain (1983).

Collis, et al.'s finding that sex-role stereotyping may lead to fewer women entering the field may account for the disparity in the number of females to males in the classes studied. Since the courses studied are designed to be for people entering computer science rather than general users.

Summary of Findings.

No statistically significant difference was found in relation to gender and interface used. There was an intriguing incident for students who changed interface during their studies, but this too may be insignificant in light of possibly confounding factors.

The general indication is that a change in interface, from CLI to GUI, may serve as a stabalizing factor on a student's grade as they advance through computer science courses.

Call for Research.

The questions being studied for this research remain unanswered and still of importance for the future of computing research. This study also suffers from the factors that grades in the classes studied are subject to curves by the instructors, and thus if GUI or CLI had an overall effect on the entire population, or if gender balancing was undertaken by the instructor, real differences in the interfaces would not be apparent from the methods used for this study.

The development of a computer usability test that could be administered before and after interface changes or to independent groups is considered a priority by this researcher. Such a test could measure possible differences between the usability of interfaces and their effect on gender and provide better data for analysis of such issues.

Future research on the question of interface differences should seek to use a better method for quantification than class grades, especially when final class grades can often have such large standard deviations as was shown here.

Quasi-experiments may be able to provide indications of possible differences in interface if they exist, and could add to the evidence that there is no difference in interface if that is the case. Entrance and exit testing of students in similar courses using an interface knowledge or preference test such as the one called for above may be sufficient to provide evidence for gender bias in interface. However, any constructed test will have all the possible biases that comfound any testing apparatus, such as bias for or against CLI or GUI. This researcher considers that the question of the effects of changing from first GUI to CLI centered instruction also would be enlightening, but no feasible method for gathering the appropriate data was found.

Appendix 1.

Historical analysis of computer interfaces.

For future researchers to categorize the possible effects of interfaces in their research and more clearly define the field of interfaces it is important to know when certain interfaces were invented and when they became prevalent. A terminology is provided here to differentiate interfaces and determine which fall within the above defined and broad categories of GUI and CLI.

The following are the working categories that are be used in this study of interfaces in computational (computer) devices. The basic rule for determining the end of an era is when half the buyers of new interfaces have changed to buying the newer technology and interface. A current example is the great rush of buyers to purchase Microsoft Windows 3.0 when it was released in the summer of 1990, the purchases of this program were greater than the purchases of the classical CLIs of the same period, and though the statistics are not definitive and trends are reversible, it would appear that graphical interfaces will continue to outsell the CLIs presently on the market.

The names of important figures in the development of technology and machinery used during each era are included to help researchers research theoretical developments and ideas behind the developments. It is important to note that the figures will usually proceed the era since eras are defined by the sale or use rather than by the period of innovation.

The works of Augarten (1984), Evans (1981), and Jennings (1990) were indispensable in identifying the major figures and examples of each period. To separate their contributions at each instance would be impossible as much information is duplicated in their research. These three author's works are the most comprehensive histories of the development of computing in Western Europe and America.

In tracing the history of interfaces and computers it is often difficult to separate the contradictory information contained in various historians' works. Wherever possible, notes have been made on contradictory claims for the achievements noted here. It is also important to note that all the published English—language histories available to this researcher concentrate on the Western European and American history of technology. The development of computing systems in other areas of the world is not considered here.

Insert Table 4 about here

The survey of traits proceeds in chronological order, starting with the tabular and columnar interfaces that were prevalent until 1955 in both print and mechanical forms.

Tabular Era; From Antiquity to 1700.

Traits of this era.

Directly read mathematical tables must be considered the first step toward computers. Both addition and multiplication tables were prevalent through the 1800s when they were superseded by public education / memorization and logarithmic tables. The abacus falls within this era due to the training needed in how and when to move the beads into their respective positions to indicate multiplication and division. The abacus is a method of notation much as Roman numerals are, not an adding device; the operation of the abacus is virtually the same as the systematized addition taught to many students in schools today including regrouping (carrying).

As a historical footnote it is important to note Napier's Bones which falls into this category though they, in many ways, share some physical characteristics of gear driven computing devices. The distinction between the tabular era and the mechanical era becomes clear when 19th century improvement on Napier's Bones, by Genaille is considered. Genaille's bones removed obstacles of procedural knowledge and allowed the bones to directly display the answer, once arranged in the desired order (Randeli, citing Nicoladze (1928) and Genaille (1878)). Genalie's rods and the electromechanical machine described in Nicoladze appear to belong to the mechanical era because the results can be directly read from both devices (They do not require addition by the user, and thus can do more than the table-building, Napier's Bones).

Major Figures and Examples.

John Napier developed logarithms and publicized their usefulness starting in 1614. Napier's bones allowed people to develop their own tables for multiplication of large numbers. The bones are not considered mechanical because the user still must add the numbers on the various rods together to achieve the final answer.

Mechanical Era; from 1700 to 1955.

Traits of this era.

Input, processing, and output are three clearly separated functions of the machinery in this era. Dials are set to indicate the numbers to be summed, multiplied, or otherwise processed, and the results are displayed on a separate set of dials after the user, or a motor, cranks processing levers and handles appropriately. Often a bell would sound to indicate that the cranking could stop.

Pre—electronic computers generally used dials to display their essential data. While information was fed by means of punch cards filled with data or instructions. Punch cards continued to be a feature of computers into the 1970s and are still used in some places. The second possible interface category from this era is best exemplified by Pascal's calculator which is very similar to the odometers of today's automobiles. In both the punch card or Pascal's system the gears of a machine turn to keep count and display their answer or data by the physical position of their parts.

The 1700 starting date for this era comes from Aiken's note of the wide use and acceptance of the slide—rule by this date. Aiken quoted in Randell (1975), p. 191. The use and purchase of tables continue to be strong past this date although no sales figures are available.

Major Figures and Examples.

William Oughthred introduced the slide rule for multiplication and division. The slide rule thus must be considered the first directly read mechanical math machine. He is also credited with naming the trigonometric functions and introducing the x as a symbol for multiplication. (Stine (1985), p. 50 credits John Napier with the invention of the Slide Rule while Goldstine (1970), Augarten (1984) and Evans (1981) credit William Oughthred.)

Blaise Pascal was the person who first mechanized addition and subtraction in modern Europe. Pascal's Pascaline was developed between 1642 and 1644. Goldstein (1970), p.6, notes letters between Johannes Kepler and Wilhelm Schickard that indicate that Schickard had designed machines capable of adding, subtracting, multiplying and dividing by 1624. Goldstein (p. 271) a;lso notes Charles, 3rd Earl of

Stanhope's contributions to logic processing. And, Stanhope is credited with the development of mechanized multiplication in Augarten (1984). And Samuel Moreland or Morland is given primary credit for this accomplishment by Aiken, p. 191 quoted in Randell (1975), and by Randell in his introduction to his own work, p. 2.

Joseph—Marie Jaquard was an inspiration for punch card readers and storage with his Jaquard loom. His techniques became well publicized and he may have inspired Babbage and Hollerith's use of punch cards for storage. However, Randell (1975) rejects this common assertion (p. 5). Jaquard himself may have been influenced by music boxes of the day or the player piano that was already touring Europe (Stine, 1985, p. 37).

George Boole integrated the field of logic into mathematics with his An Investigation of the Laws of Thought on which are Founded on the Mathematical Theories of Logic and Probabilities and thus helped inspire the mechanical proof of logic theorems.

Gottfried Wilhelm Leibnitz first combined multiplication and addition into a single machine with input and output fields for each being shared. Liebnitz also considered alternate base mathematics (such as octal and binary) but became distracted by the philosophical ramifications of numbers being able to be represented by binary digits and never pursued the mechanical implementation of his findings.

Charles Babbage helped to translate Leibnitz's works on calculus into English and sponsored the change to d—notation for calculus at Oxford. More importantly in 1822 Babbage developed the difference engine to help form reliable mathematical tables. The difference engine in its partially completed form was capable of extracting the roots of quadratic equations (Stein, 1985; quoting Ada Byron Lovlace's mother's description of the machine). Abandoning his work on the difference engine he moved on to the analytical engine which, as conceived, could store numbers and read punch cards to simplify the input of numbers. Unfortunately, his constant striving for improvement lead to numerous revisions of the design and the intricate design specifications delayed the work (Stein, 1985). Many historians believe the precision necessary for the mechanism was beyond the abilities of the craftsmen of his day.

Augusta Ada Byron, Countess of Lovelace, is considered the first computer programmer due to her vision of stored instruction possibilities within Babbage's Analytical Engine. She suggested to Babbage that not only the numbers but also the equations be stored and be manipulatable. (Stein, 1985)

Herman Hollerith's tabulator used for the 1890 U.S. Census (and previously by the City of Baltimore to calculate their vital statistics) was the first data processor that achieved much public attention. His tabulator also was one of the first to use electric switches to augment the mechanical tabulation of data. (Stine, 1985; p. 39—51)

Electronic Native Data Modes; from 1955 to 1962.

Traits of this era.

The computers of this interface category include some of the earliest electronic computers. Their distinguishing feature is their inability to simulate natural language (Natural language is defined in appendix 2.) for interfacing. They were generally fed data and instructions by punch cards, or paper—tape created by mechanical or electromechanical devices not physically connected to the computing device.

The results of instructions were generally read from illuminated displays where each light represented a data bit, and where natural language characters were not formed by the lights. Results also could be printed onto punch cards and read in separate card readers that electromechanically converted the language into natural language printouts, thus foreshadowing the next era.

It is important to note that most analog computers should fall into this category, and that they are often coupled to digital computers for output functions. Electronic analog computers are categorized with this era both because they do not use natural language characters to communicate and that their high—use period falls during this era of history (1955—1962). It is tempting to categorize analog computers totally separate from the development of digital computers which are significant to this study. However, it is useful to study analog computers for some classroom exercises to note the role they played and their comparative accuracy and ease of use when compared to digital computers in many mathematical calculations, especially calculus. For a definition of analog computers see appendix 2, Computer, analog.

Major Figures and Examples.

Charles Sanders Pierce first sketched electrical circuits capable of symbolic logic (Stine, 1985; p. 272—3). His work was revived by Claude Shannon for use in relay based computers. Pierce gave the idea for circuits to perform symbolic logic to Allan Marquand for application in Manquard's machine to solve logical syllogisms.

Konrad Zuse developed a relay based electromechanical memory computer that used papertape—like (actually 35mm movie film) storage. He was also one of the first to consider the use of valves (Vacuum Tubes, as they are known to Americans, are called Electronic valves in Britain and Europe.) tubes for switching, his final working computer was the Z4 that he built during World War II (Evans, 1985 and Augarten, 1984 differ on whether this last model was called the Z3 or Z4.).

Credit for developing the *Electronic tube* goes to Thomas Edison's assistant Sir John Ambrose Flemming with major improvements added by Dr. Lee DeForrest near the turn of the 20th Century. Stein, p. 60—62. Electronic tubes or valves have also been generically called triodes and audions at various times.

Howard H. Aiken, a Harvard professor, independently arrived at ideas similar to those of Zuse's Z4. Aiken's machine was named the Mark I and is remarkable for using a modified teletype for input.

The British Government's Foreign Office's Department of Communications team of code breakers at *Bletchley Park*, a manor outside London, built the Robinson series and finally the Collosis series of computers to break German codes during World War II. Collosis computers used extremely high—speed papertape readers for much of their input, output and storage.

Alan Turing was a member of the Bletchley Park staff and is considered one of the earliest computer scientists for his contributions to Robinson series of computers and the field of Artificial Intelligence.

ENIAC (the Electronic Numerical Integrator And Computer) was the first of the well publicized computers in the United States. ENIAC was developed by the Moore School of Electrical Engineering, a part of the University of Pennsylvania. The interface for ENIAC was primarily punch cards with patch boards for monitoring the progress of the machine in its calculations. A detailed description of the ENIAC, authored by H.H. and Adele Goldstine, can be found in Russell, p. 337—347.

Teletype Singleline; from 1962 to 1968.

Traits of this era.

This is the first of the interface eras that is considered CLI based for the purposes of this study. The computers of this era are distinguished by their ability to accept and parse single lines of instructions entered from an input/output device generally similar to the teletype machines of this era. A detailed explanation of the combined use of papertape, punch cards and typewriter output can be found in Howard H. Aiken and Grace M. Hopper's papers on the "Automatic Sequence Controlled Calculator" reproduced in Randell, p. 199—218.

Instructions could be entered into their systems using mnemonics for machine instructions. These machines became the first machines to have programming languages, both compiled and interpretive, written for them (Evans, 1981; p. 60—67).

Major Figures and Examples.

Western Union had developed papertape readers and encrypting typewriter for telegraph use before the time the computer designers were starting to integrate them into the computer systems. A discussion of text input and output to teletypes can be found in deBry, p. 49-68.

The Bell Labs Modell calculator was one of the first computers to use a keyboard for input, it features a modified teletype with the keys necessary for mathematical functions to be input into the calculator.

The *SABRE* network, first sold for business subscribers around 1954, was the first national communications system to integrate information processing and retrieval with teletype interfaces for its users around the country.

The *UNIVAC* computer, developed by the Remmington Rand Division of the Sperry Rand Corporation, used a teletype terminal and magnetic tape for input and output; and may be considered the innovator that influenced all further interface design until the graphical user interface was developed. UNIVAC was first delivered to the Bureau of Census in 1951 and was an industry standard for several years.

Full Screen functions; 1968 to 1984.

Traits of this era.

The machines of this era include character generation hardware and video signal generators to place the text that had previously been printed on paper onto a screen display. This interface is still common for mainframe computers and the IBM—PC series of computers which are not using graphics adaptor cards (Evans, 1981).

While full screen editing is often considered a significant move beyond the single—line editor; these machines are grouped with and called CLI computers for the sake of this study. The instructions used on these computers are generally written on a single command line with the ability to wrap text around to the next line on the screen. Even in word processing applications, the functionality of the programs is based on editing the single line that the text is on and only checking the other lines of the document when the edited line's characteristics change significantly. Programs where such line functionality in full screen editing is well displayed are: EDLIN under MS—DOS or IBM—DOS; Wordstar (versions 1 through 3) on CP/M and MS—DOS computers; XEDIT on CP/CMS computers; and ED, EDIT or VI on Unix based computers.

Though CRTs are most associated with this era's displays it is important to note that CRTs were also used by earlier computers in a role similar to RAM chips in today's computers. From this it is important to note the fact that CRTs are present does not necessarily indicate that they were used as a part of the interface.

Major Figures and Examples.

The *Bell Labs* team, of John Bardeen, Walter Brattan and William B. Shockley, developed the solid state transistor in 1947. The transistor was essential for the future development that lead to the personal computers studied here. It also made higher processing speeds and therefore real—time monitoring of computer functions feasible. Bardeen has continued his electronics work and is also a significant player in superconductivity research.

Jack Kirby of Texas Instruments developed the integrated circuit in 1958 this was a major achievement that helped to miniaturize the computer and improve on its speed. Since the mass production of ICs began, in the mid—1970s they have found their way into almost every corner of technological society from car engines to microwave ovens to toilets.(Lui, reports a toilet that analyses urine and tracks users health for up to 130 examinations. Quoting Kyoto News, 24 March 1990, no page number given).

M.I.T.'s Whirlwind computer, developed for U.S. Air Force radar targeting, in 1956 was an early user of CRT's for text and data display. The development of picture signal refresh circuitry was an essential developments for CRT data displays to be useful for computer use (deBry, 1985). Field (line) based editing techniques on a fullscreen display are also discussed in deBry, p. 117—119.

Since *Whirlwind*, CRT displays have become standard features of computers. The VAX—11/786, PDP—1, IBM—370, Control Data 6600 all used CRTs for data display in their early implementations.

Single—key to Icon Translation; from 1984 to 1990.

Traits of this era.

During the early—1980s, hardware and software developers began making these CLI based computers more functional by introducing the ability of making a single key represent an action for the computer to execute. Often, these key instructions were displayed at the bottom of the screen to help users remember what each key stood for.

With the introduction of graphics abilities into most computers sold, the function—key reminders began to take on iconographic forms. For example, a picture of a printer would be displayed on the screen with the name of the function key that makes the program print. The graphical abilities also invited a change in the interface device toward the mouse or graphics tablet so that graphics could be more easily developed on the screen without numerous keystrokes.

By 1987 exclusively graphical interface computers, (defined in appendix 2.) had become a strong force in the marketplace and many text—based programs began to feature pop—down menus and other features that were first made commonplace on graphical interface computers.

Major Figures and Examples.

Xerox Corporation's Palo Alto Research Center (PARC) first developed many of the concepts used in the graphical user interface under their STAR project. The results of the PARC research congealed the high resolution screen display, icons and windows as the central display paradigms for this and the next era of computers.

Steve Jobs, who worked as a summer intern at PARC was so impressed by the Xerox project that he moved toward developing a similar interface for his upshoot computer company called Apple. The result was the Lisa, which belongs with the next era of computers. Lisa's poor sales, and Apple's choice to develop and support the Macintosh computer finally forced it out of the market.

Graphical (2—D) User Interface; from1990 to present.

Traits of this era.

The best example of these computers that has become known to the public is the Apple Macintosh. The primary interface for non—text work is the mouse and most of the computer's functions can be completed by the mouse. There are also some functions that can not be completed without a mouse or special programs. These computers often feature hardware thaty requires the graphics circuitry to be in use in order to complete routine operations. For example QuickDraw must be active for the Macintosh to show text on its screen.

Major Figures and Examples.

Macintosh computers by Apple Computer, the successor to the Lisa Computer that has become the definitive graphical user interface for personal computers. Its paradigms are stronly based on STAR research and have been copied by numerous other companies starting a round of litigation which has yet to be untangled.

Windows 3.0 by Microsoft, a revision of earlier software by Microsoft that became a sales success for the IBM—PC family of computers. This is the first graphical interface that captured a strong foothold in the IBM markets, and one of the first internally programmable interfaces that allow stronger flexibility of representations on the screen.

3—D virtual reality; in the future.

Traits of this era.

Current experimentation in the field of user environments and interfaces seeks to stimulate as many of the user's senses as possible. The 1991 applications of this technology include stereo glasses that simulate 3—D vision, stereo sound equipment which helps the user locate sounds, tactile simulators that let the hand feel as though it is touching or holding an object, and directional treadmills that allow the user to walk through the environment being simulated with the other devices.

Major Figures and Examples.

Many researchers are involved in the possibility of virtual reality and none have distinguished themselves at this time. Major centers for the research are: The University of California at Berkeley, Queens College in England and the Massachusetts Institute of Technology.

A well organized list of organizations and people researching new interfaces as of 1985 can be found in Appendix II of Christie (1985).

Forthcoming interfaces.

Traits of this era.

Other future hardware and interface developments of great promise are: Parallel computing, superconducting circuitry and as mentioned above optical processing and computing circuitry. Input device developments being pursued are speech recognition – even with speech's apparent lack of speed for many operations (Christie, 1985; p. 76), biofeedback and encephalograph reading, refinements in light pen and touch—screen technology are also promised. Output devices continue to decline in price with greater resolution and accuracy in their displays, results and communication efficiency (i.e., True Type, Postscript, and PCL5 are examples of efficiency improvements over the bit—map system used in early printer control.)

Many different computing devices are being studied beyond those mentioned above. At present there are strong arguments for and against the possibilities of replacing the wires of today's computer with purely optical switching and logical devices, this change may reduce the sizes of computer parts and make computers faster (Jennings, 1990; p. 222—3). At the time of this writing optical transistors, often considered the first step toward optical computers, have been reported to have been developed but remain bulky and not feasible for real world applications.

Software developments are another field of interface research. The promises of fully customizible interfaces are far from being reality and so—called "smart" computers that remember and make valid assumptions based on past input and user actions are also in the infancy of development.

Major Figures and Examples.

A well organized list of organizations and people researching new interfaces as of 1985 can be found in Appendix II of Christie (1985).

Appendix 2

Working Term Definitions.

Computers.

"...devices which represent numbers or quantities as physical states. Physical states being a gear in a particular position, a lever up or down, a switch on or off, the presence or absence of an electrical charge in a vacuum tube, a current pulsating in a wire, a magnetic substance in a magnetized or unmagnetized condition..." (Evans, 1981; p. 33)

Computer, analog.

"A computer that solves problems by operating on continuous variables that represent continuous data . . . Various types of amplifiers, properly connected, perform various kinds of arithmetic operations, such as summation, multiplication, integration and differentiation. Accuracy is limited by the precision with which parts can be made, and the extent to which electrical circuit elements change with environmental variations such as temperature, whereas the precision of a digital computer is dependent upon the number of digit positions handled by the computer's components...Analog systems are usually faster than digital systems, since only electrical propagation time through the system limits the speed." (Weik, 1970; p. 80)

Computer, digital.

"A computer that solves problems by operating on variables expressed as data in discrete form and by performing arithmetic and logic operations on these data." (Weik, 1970; p. 81)

Computing.

The process of using a computer, a level of skill that allows the user to achieve their goals in using a computer in a gratifying amount of time. The amount of time taken is subjective by user.

Exclusively graphical interface computers

Computers with no native character to video translation abilities without the graphics interface being engaged and used to "draw" the characters first. (i.e., The Apple Macintosh.)

Graphical User Interface (GUI).

Any of several computer interfaces based on letting users visually understand the manipulations being performed. As of 1990 most of these systems use the mouse as the primary input device and use the keyboard primarily for naming items and entering data/text based items.

The computer most people associate with this interface is the Apple Macintosh line of computers. In spite of this, graphical interfaces are now available for many computer systems: Microsoft Windows 3.0 for the IBM—PC line of computers is another well known example; lesser known and used GUI interfaces are the Amiga and Atari ST standard interface, GEM for IBM—PCs, GS—OS for Apple IIGS computers, and Deskmate applications for Tandy Computers.

Many of the conceptual elements of how today's graphical interfaces work are explicitly expressed in Apple Computer's reference book Human Interface Guidelines, (1987). Some examples of the ideas expressed in that book are:

Users select actions from alternatives presented on the screen.

Users rely on recognition, not recall; they shouldn't have to remember anything the computer already knows. (p. 4)

Keep the user informed.

Provide Immediate Feedback [to the user].

The activities should be simple [as perceived by the user] at any moment, though they may be complex taken together. (p. 7)

The credit for developing the basic ideas behind most of todays' graphical interface can be credited to the Xerox Corporation's Smalltalk and Star projects undertaken at the Xerox Palo Alto Research Center (PARC). The PARC researchers developed icon and mouse based interfaces for their personal computers in the mid 1970s. High resolution monitors that display "windows" of data is the primary development from the PARC research (Bolt, 1984; p. 25—26).

Other graphical user interfaces have been examined, but most would not be appropriate for personal computer use as it is known today. The strongest of these and the most often cited in literature is the Massachusetts Institute of Technology's Dataland that evolved into the Computer Corporation of America's (also based in Cambridge, Massachusetts) system for screen representations of data. This graphical interface used involves a large computer screen (M.I.T. used a wall sized projection) and smaller screens to display the necessary data once it was selected from the larger screen.

Interface.

The device, or arrangement of devices that allow the user to instruct the computer or calculating device what instructions it should carry out and for the computer to communicate to the user the results of their instructions.

Weik (1970, p. 167) defined interfaces as: "A shared boundary; for example... the boundary between a person using an information system and the input or output station itself.... If the system is to be useful, it must interface with something outside itself, such as humans, its environment, materials, or another system."

The interface's devices can be knobs, switches, buttons or any other object that may signal a computer of the user's intentions. Keyboards, light pens, mouses, printers, and television screens "television screens" is the colloquial term, used for simplicity. Computer Scientists will more often call this category of device a Video Display Terminal (VDT), Cathode Ray Tube (CRT), monitor, or screen.

are all examples of interface devices. The devices may be physically real or virtually real in that the user feels as though they are directly or indirectly manipulating the device in question. For example: a button drawn on the computer screen may be considered a device since the user feels as though he or she is directly manipulating it, much as they would a button on a control console.

Line—editor based interface.

Any interface where commands are entered primarily from the keyboard in sequential order based on horizontal lines of text with each line of text being a different command or response.

The computers most people associate with this form of interface is the IBM—PC operating under MS—DOS 3.3 or earlier. Other examples of the interface include

ProDOS on the Apple II line of computers, CP/M on Z—80 based machines, most Unix terminals and CMS/CP or VMS based mainframes.

This interface was originated in the early days of electronic computing by multiple organizations who were adapted typewriter—like devices to computer input. Keys on the typewriter keyboard would correspond to holes in punch cards or paper—tape that had, until that time, served as the direct interface to the computer.

Natural language.

"A language whose syntax reflects and describes current usage rather than prescribed usage. The rules are developed ex post facto. The language evolves from usage [while] an artificial language is determined prior to usage." (Weik, 1970; p. 174)

Natural language is the term for languages intended to be used for interpersonal communication that are the outcome of the process of linguistic evolution. Planned languages (i.e., Esperanto, Ido, Loglan, etc.) and computer programming languages (BASIC, FORTRAN, C, Assembler, etc.) are not considered natural languages.

User.

The person using a computer to provide the computer with data and other input. This term is colloquially applied to people who are not programmers but for the purposes of this study it refers to all people who interact with computers.

Edsgar Dijkstra, a well respected figure in today's computer society, defines a computer user differently:

"The computer "user" isn't a real person of flesh and blood, with passions and brains. No, he is a mythical figure, and not a very pleasant one either; a kind of mongrel with money but without taste. An ugly caricature that is very uninspiring to work for. He is, as a matter of fact, such an uninspiring idiot that his stupidity alone is sufficient explanation for the ugliness of most computer systems..." (Dijkstra, 1982; p. 289)

Dijkstra's comment is tongue in cheek humor, but it expresses some of the exasperation the computer community feels in trying to define who will be using their programs and how poorly they are often used.

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Table 1.

Population of CSCI 311 and 312 by gender and semester:

	CSCI 311	CSCI 312
Semester	Male / Female	Male / Female
Fall 1987	28 / 10	Not Offered
Spring 1988	18 / 7	17 / 5
Fall 1988	34 / 7	4 / 3
Spring 1989	8 / 3	25 / 1
Fall 1989	21 / 14	5 / 2
Spring 1990	10 / 2	14 / 8
Fall 1990	33 / 12	3 / 0

Table 2.

Average grades by gender and interface:

Gender	using CLI	using GUI
Male	**2.702** (sd= 1.254)	**2.801** (sd= 1.157)
Female	**3.042** (sd= 0.884)	**2.696** (sd= 1.232)
Combined	**2.790** (sd= 1.179)	**2.775** (sd= 1.178)

Table 3.

Predicatability of grade change from CSCI 311 to CSCI 312 by interface:

	Interface and class number		
Change	CLI 311 to CLI 312	CLI 311 to GUI 312	GUI 311 to GUI 312
≥ +1.66	1 (3.5%)	0 (0%)	0 (0%)
+1.33	1 (3.5%)	0 (0%)	0 (0%)
+1.00	2 (7.1%)	0 (0%)	0 (0%)
+0.66	3 (10.7%)	1 (8.3%)	1 (3.6%)
+0.33	2 (7.1%)	0 (0%)	1 (3.6%)
0.00	, 7 (25%)	6 (50.0%)	11 (39.3%)
- 0.33	3 (10.7%)	2 (16.7%)	2 (7.1%)
-0.66	3 (10.7%)	2 (16.7%)	2 (7.1%)
-1.00	0 (0%)	0 (0%)	6 (21.4%)
-1.33	0 (0%)	0 (0%)	1 (3.6%)
≥ -1.66	4 (14.3%)	1 (8.3%)	4 (14.3%)

Table 4.

History of Computer Interfaces, Categorized and Listed Chronologically

Interface Era

Title	Years Prevalent
Dial-based or columar	
Tabular	antiquity to 1700
Mechanical	1700 to 1955
Electronic Native Data Modes	1955 to 1962
Line-based	
Teletype Singleline	1962 to 1968
Full Screen Functions	1968 to 1984
Single-key to Icon	1984 to 1990
Graphical	
Graphical (2-D)	1990 to future
3-D, Virtual Reality	future

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