An Investigation of the Longitudinal Effects of Network Latency on Pedagogic Efficacy: A Comparison of Disciplines

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ABSTRACT

Interactive web-based learning tools, such as engineering simulations, are becoming increasingly common. Universities find them cost-effective, and students find them convenient. Professors find web-based simulations effective to intuitively convey the complex cause-and-effect relationships that are central in engineering education. For example, moving a slider can be used to interactively see how changing a resistor's value changes current flow through a current divider. There are many studies investigating the effectiveness of interactive web-based learning materials, yet, little systematic investigation of the pedagogic impact of network delay. This paper, therefore, seeks to quantify the relationship that network latency, or delay, has upon student enjoyment and student comprehension. An interactive software application was designed purportedly to teach Fourier Analysis concepts, but embeds a hidden delay between the time a student moves one of the interactive controls and the time that the screen updates. Different versions of the application were designed, each identical except for the delay. Students were randomly assigned application versions, ensuring double-blind test conditions. Students used the application while completing a short guided lesson that used the Socratic Method to intuitively teach Fourier Analysis. After completing the tutorial questions, which provide an objective assessment of student comprehension, students self-rated their comprehension and enjoyment, and recorded their program version number which encoded the delay. The data was least-squares fit to several different functions with varying degrees of freedom and residuals were computed. Data involving 281 students from four universities and one high school using eight equally spaced delays from 0 to 420 ms was analyzed. Student objective comprehension, as measured by an objective test following a learning experience with one of these Fourier Analysis programs, was compared to their self-reported comprehension estimate, and their self-reported enjoyment.

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Relationships were compared between students in technical majors or humanities and social sciences. The study suggests that the accumulation of experience and choice of major are important factors in mitigating the effects of network delay on learning.

Keywords: Academic disciplines; e-learning; enjoyment; feedback delay; latency; learning styles; network delay; objective learning; pedagogical efficacy; self-reported learning.

1. INTRODUCTION

According to Allen and Seaman [1], enrolment has grown more quickly than overall higher education enrollment. According to Dollar and Steif [2], Reisel et al. [3], interactive web-based learning aids like engineering simulations and mathematics tutorials have recently surpassed textbooks in popularity as resources for undergraduate education. With 61 percent of two-year and four-year educational institutions offering online courses as of the 2006–2007 academic year, Parsad and Lewis [4] report that web-based educational software has propelled online courses out of traditional classrooms and into the mainstream. The Sloan Consortium Annual Report states that 3.9 million students were taking on-line courses in 2007, Allen and Seaman [5], and that by the fall semester of 2010 this number had risen to 6.1 million, Allen and Seaman [6]. While the ranks of students involved in some form of web based education expands every year, the effects of the physical limitations of the internet, such as bandwidth combined with network delay, on learning is only partially understood.

Allen and Seaman [7] reported in a ten year study on online education in the United States discussed the concerns facing online education in the United States. Specifically, they reported three critical barriers when adopting online education. The need for online students to be more disciplined has been cited by 88.8 percent of academic leaders in their survey, which is an approximately 10 increase in their concern over ten years. Following from the first concern, the majority of chief academic officers perceived that the retention rate is lower for online courses. The last concern is focused on the acceptability of online degrees in the marketplace. Approximately forty percent of academic leaders indicate that potentials employers' lack of acceptance of online degrees is a barrier to online education, which has not yet change. However, the study indicates that academic leaders see online education has a critical component to their long-term strategy is at an all-time high of 69.1 percent.

Four years ago, during the 2007-2008 academic year, a systematic study was conducted to address this topic using a web-based Fourier synthesis tutorial with an initial sample of 281 students to characterize the effects of network delay on learning [8,9,10,11]. Students were provided with one of eight possible versions of an interactive tutorial, each of which was coded with a particular delay. Students were then presented with a set of conceptual questions about Fourier synthesis and instructed to use their version of the tutorial interactively to answer the questions. Students were also queried as to their enjoyment of the learning

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experience [12-14], as well as how confident they were about their answers to the conceptual questions. Based on this data, an initial assessment as to the effect of network delays on objective learning scores, self-assessed learning and enjoyment were made. In general, it was found that the group as a whole was fairly intolerant to delay for objective learning, with scores falling off at delays of 60 ms; the smallest non-zero delay in the study. In contrast to the objective learning results, enjoyment declined gradually with increasing delays, and self-assessed learning ratings only decreased for delays greater than 300 ms.

The purpose of this paper is to report on the outcomes of a longitudinal study started in the fall semester of 2008. Of the students who participated in the study during their freshmen year, 113 were enrolled in the spring semester of their senior year and willing to participate again in the study. Not all of the initial participants were enrolled at the institution and others were not enticed by the rewards, a free pizza and a chance for a fifty-dollar gift certificate at a local restaurant. Originally, each participant was randomly assigned a version of the Fourier synthesis tutorial and asked to use the tutorial to answer the same questions posed in the original study. They were reintroduced to the Fourier synthesis tutorial as seniors, with each student receiving the identical version of the tutorial that they used as freshmen. As in the original study, students' performance on the Fourier synthesis tutorial was assessed using measures of objective learning, subjective learning and enjoyment. In addition to examining the effect of delay time on these measures, the notion of a self-critique measure is introduced as a means to gage changes in the learning characteristics of the students over time.

2. RESULTS OF PREVIOUS WORK

In the original study [11], 281 students from four different universities participated. One hundred fifty-five students identified their major as engineering or sciences, 96 stated their major as humanities and 30 did not specify a single major. The age range of participants was 15-25 years of age, with a mean age of 19.15 years, and 86 percent of the students were male.

A C# interactive software application containing a hidden delay was created for the experiment, with eight different versions corresponding to delays of 0 ms to 420 ms in increments of 60 ms. The program can be downloaded at:

https://www.jimsquire.com/research/phasors/phasors.htm

Students were randomly assigned a version of the Fourier synthesis tutorial and then were given a questionnaire to work on interactively with the tutorial program. The questionnaire consisted of 6 personal information questions to establish information about the students such as their age, gender and academic major, as well as 11 questions concerning Fourier analysis concepts and two questions related to students' enjoyment of the tutorial, and their confidence in the answers they gave. Data from questionnaires was tabulated using a MATLAB program and used to calculate three measures of learning with the interactive tutorial:

- Objective learning: The proportion of correct answers from the 11 conceptual questions.

- Subjective Learning: How well the students felt that they performed on the 11 conceptual questions. Scoring was based on Likert scale where 5 corresponded to "very confident" in their responses and 1 corresponded to "not sure at all".

- Subjective Enjoyment: Scoring was based on a Likert scale with 5 representing the most enjoyment and 1 the least enjoyment.

In each case the mean values of these measures were calculated and plotted against the delay time. The error bars on each of the plots are given as +/- the standard deviation of the measurements. Bilinear models were fit to the data to identify the "elbows" of the various learning measures as a function of delay. In general objective learning scores were the most sensitive to network delays with a 10% drop for delays 60ms or higher. Subjective learning, (i.e. student confidence), was much less sensitive to delay, dropping steeply only for delays greater than 300 ms. Enjoyment on the other hand, decreases steadily from a high value of approximately 4.75 at 0ms delay, until it levels off at a value near 3.7 at a delay of 300ms. These results are interesting in that they point out that students may be somewhat confident about their answers and happy with the learning experience at delays which produce poor objective learning results. The study concluded that delay times must be minimized to meet objective learning goals.

Further, Bush, et al. [10] reported that the tolerance for screen update latencies were greater for students who were in non-technical majors (humanities and social sciences) than those in technical majors (engineering and sciences) in terms of objective learning, subjective learning, and enjoyment. The investigation of the change in the interaction of objective learning and subjective learning was identified in a preliminary investigation [8].

3. RESULTS OF THE LONGITUDINAL STUDY

The original experiment was expanded to collect data from entering freshmen for three years (2007 through 2009) and then again three years later in the spring of their senior year (2011 through 2013). Of the students who were tested originally, 113 students agreed to participate a second time motivated by a free pizza coupon and the chance to win a gift certificate to a local restaurant.

As freshmen, students were randomly assigned to an interactive software application based on the Fourier synthesis with an imbedded screen delay from 0 to 420 milliseconds in increments of 60 milliseconds. As seniors they were specifically assigned to the same group. Each time the students were provided a tutorial and a questionnaire which provided the responses to process the measures of objective learning, subjective learning and enjoyment.

To investigate the longitudinal impact of the different levels of screen update delayed on the interaction of objective learning and subjective learning, objective learning and enjoyment, and subjective learning and enjoyment, data spaces were developed. For example, to investigate objective learning and subjective learning the data space appears in Fig. 1 [8]. Ideally, students' perception of their learning should be consistent with their objective learning. Using the scores from the objective learning questions and by normalizing the subjective learning Likert scale to a value of 0 to 1, the ideal combinations lie on a line rising at 45 degrees from the origin.
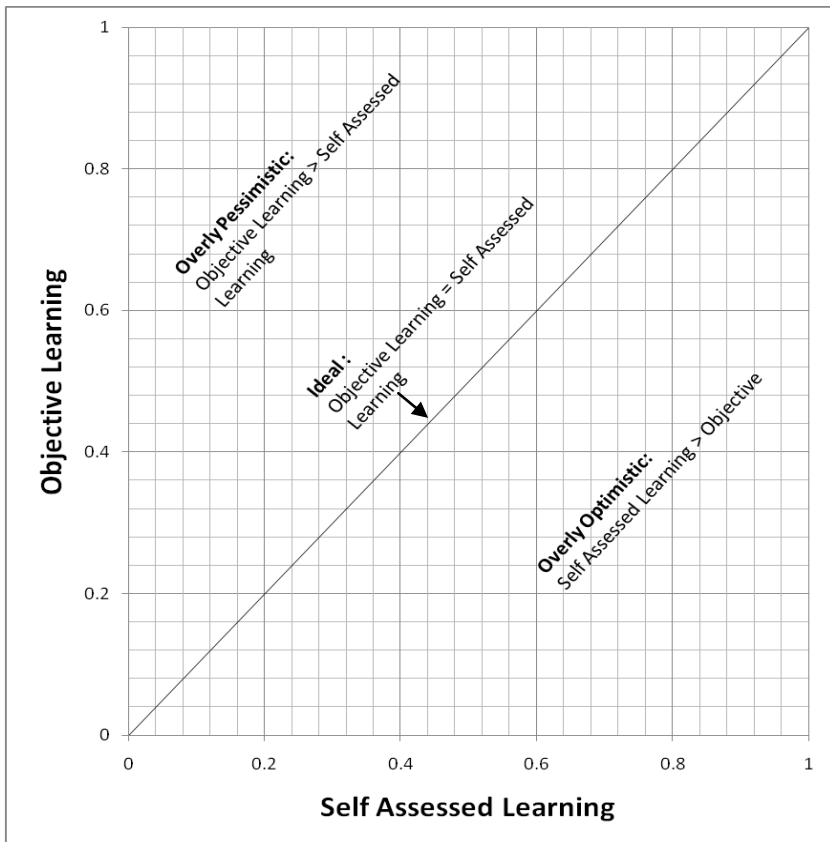

Fig. 1. An example of an interactive plot

When viewing the results, the term, "Scores as Freshmen," refer to observations from the beginning of the study and the term, "Scores as Seniors," refer to observations from the end of the study. See Fig. 1 through 10.

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The Interaction of Objective Learning and Subjective Learning

The relationship between objective learning and subjective learning cannot be assumed to be well matched [15]. The importance of the maintaining a balance between objective learning and subjective learning is demonstrated by deviations from the 45 degree line. Those individuals in the upper left-hand portion of the graph score higher than their perceptions indicate. This pessimistic view represents a lack of confidence in one's ability. Such lack of confidence could be manifested in hesitation or unwillingness to make a decision. Those individual in the lower right-hand portion of the graph perceive their abilities to be above their actual nature. This overly optimistic view represents a confidence level in excess of one's abilities. Such over confidence can lead to quick and perhaps faulty judgments. Using the data space for objective learning versus subjective learning, ideally, the observations would lie on the 45 degree line rising from the origin. (See Fig. 1.) Both situations are suboptimal. Overly optimistic learners are likely to make errors of commission by making choice from misunderstood knowledge, while overly pessimistic learners are likely to make errors of omission from failing to act from when they actually do understand the material.

To investigate the longitudinal effects on the interaction of objective learning on subjective learnings, the observations were plotted and the best fit ellipse was developed in Fig. 2. The plot reveals two key effects of the three-year college experience. First, the students' ability to understand the task has increased. The center of the ellipse has increased approximately .1 on a one point scale and the vertical span of the ellipse has decreased. Second, the students have also increased their level of pessimism. The center of the ellipse has moved further to the left of the ideal line and has a larger concentration of the ellipse to the upper left of the line. However, the horizontal span has increased indicating that more students have become overconfident. Further research would be warranted to verify that the increase lack of confidence is based on the online experience. Such a shift if maintained would imply that these students would be less prepared for decision making.

A greater understanding of the longitudinal effects can be achieved by segregating the sample populations based on the nature of their majors. As seen in Figs. 3 and 4, the plots diverge from the previous story. Fig. 3 plots the observations of the students who chose technical majors and Fig. 4 plots the observations of those who chose non-technical majors. The impact on the interaction of objective learning and subjectively learning differed for the two groups. First, although both groups increased in their understanding of the task, the students who chose a technical major experienced greater improvement in their objective learning. However, these students did not experience a proportional reduction in their subjective learning scores. The vertical movement was much greater than the than the horizontal movement of their scores. Students who chose non-technical majors had more proportionate change in their subjective learning as compared to their objective learning. The pattern of increased understanding and increased pessimism is more pronounced for students in technical majors.
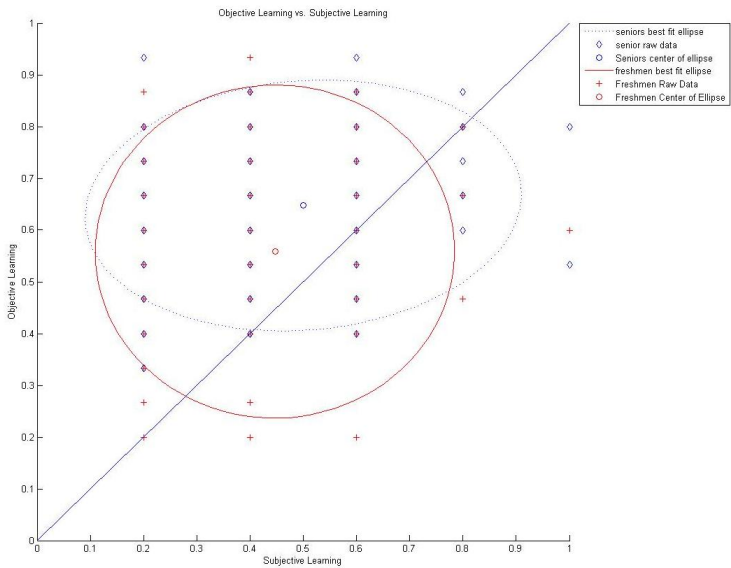
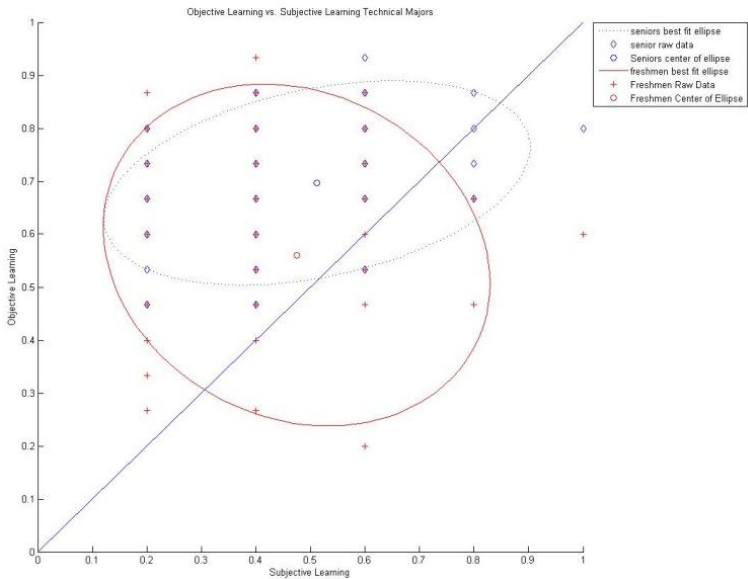**Fig. 2. Interaction of objective learning and subjective learning plot over the longitudinal study**

Fig. 3. Interaction of objective learning and subjective learning plot over the longitudinal study - Technical Majors
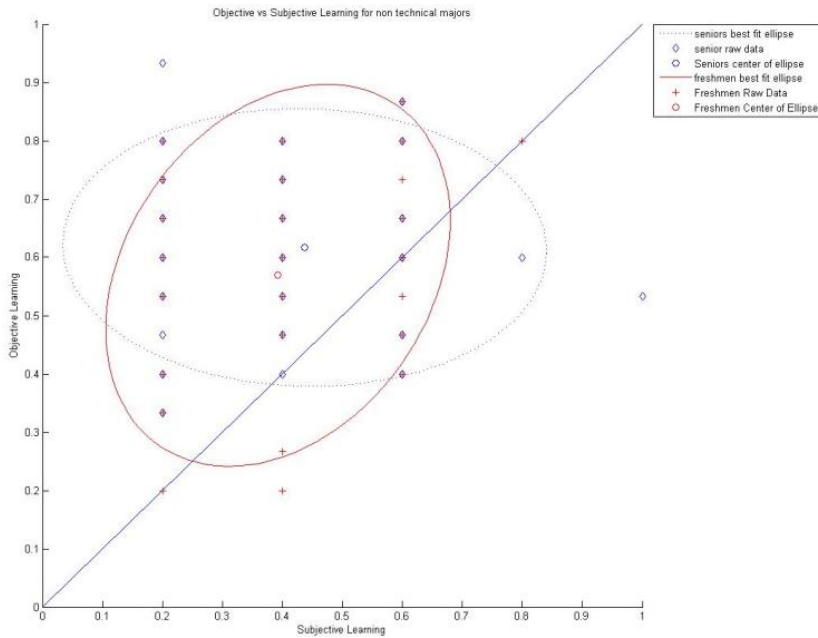
Fig. 4. Interaction of objective learning and subjective learning plot over the longitudinal study – Non-Technical Majors

Second, the area of the ellipse is indicative of the subject's sensitivity to the delay in response on the computer screen and the interaction of objective learning and subjective learning. Students who chose a technical major had become less sensitive to the delays. The area of their ellipse went from 0.3545 to 0.2216. Students who chose a non-technical major had the opposite experience. Over the three years, the size of their ellipse had increased from 0.2839 to 0.3019. The responses differed for students based on their choice of major. Given the different responses to the delay, the importance of the delay will vary among online programs.

The Interaction of Objective Learning and Enjoyment

Allen and Seaman [7] identified two barriers which concerned academic leaders when adopting online learning approaches, the need for a more discipline student and the retention rates for online courses. The tasks with higher level of enjoyment are more likely to be completed. The level of enjoyment however, needs to be matched to the level of knowledge gained. Consequently, maintaining a balance between objective learning and enjoyment is critical to the success of online learning experiences. As with objectively learning versus subjective learning, the ideal relationship lies on the 45 degree line on the objective learning versus learning plot.

The plot of the interaction of objective learning and enjoyment involves comparing a dimension which is unknown to the subject with one that is known measures a different dimension of the experience. Unlike objective versus subjective learning, where the subject is unaware of the objective learning, enjoyment is a different dimension from learning. The 45 degree line still represents an ideal tradeoff between learning and enjoyment. Observations lying in the upper left-hand corner report are not enjoying the experience but are learning. However, if the experience is undesirable, it might not be applied regularly and appropriately. Observations in the lower right-hand corner report higher enjoyment but less objective learning. The enjoyment might lead to an unhealthy reliance on the technology. Neither situation is optional.

The plot comparing objective learning versus enjoyment, Fig. 5, reveals three effects of the three-year college experience. First, the students' ability to understand the task has increased. The center of the ellipse has moved higher. Second, however, the center has also become closer to the 45 degree line. The greater increase in objective learning relative to the lesser increase in enjoyment reduces the risk associated with excess enjoyment, a greater interest in the technology than in the actual decision. Third, the area of the ellipse has decreased, indicating that the students have become less sensitive to delays in terms of the interaction of objective learning and enjoyment. The experienced gained in the three years has improved students' interaction of objective learning and enjoyment as well as decreased their sensitivity to the delays.

A greater understanding of the longitudinal effects can be achieved by segregating the sample populations based on the nature of their majors. Fig. 6 plots the observations of the students who chose technical majors and Fig. 7 plots the observations of those who chose non-technical majors. As seen in Figs. 6 and 7, the plots diverge to a lesser extent than the interaction between objective learning and subjective learning. Further both groups had several common experiences. First, both groups experienced a decrease in area from the freshmen to their senior year. In terms of the objective learning and enjoyment interaction, students demonstrated a decline in the sensitivity to the delays. Students who chose technical majors declined from 0.4617 to 0.2206 and students who chose non-technical majors declined from 0.4909 to 0.3996. Second, the interaction indicated that the objective learning score is declining relative to the enjoyment as the students become seniors. However, the impact on enjoyment indicates a difference between the two groups. Students who chose technical majors do not differ in enjoyment while students who chose non-technical majors enjoyed the experience less. This last result could possibly be driven by a task centered on Fourier series, a more familiar task for students choosing a technical major.
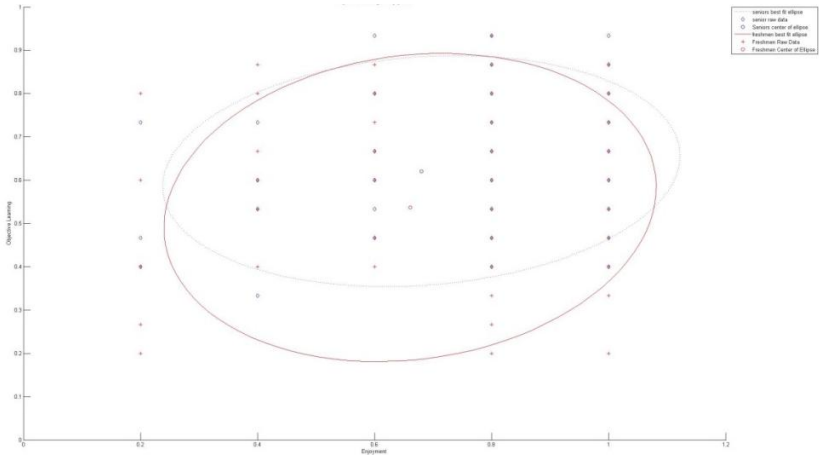
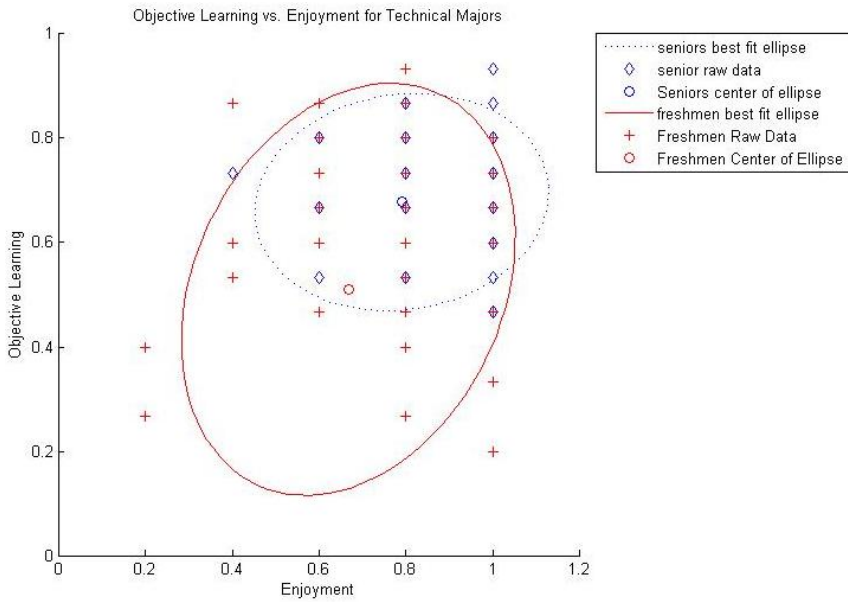**Fig. 5. Interaction of objective learning and enjoyment plot over the longitudinal study**

Fig. 6. Interaction of objective learning and enjoyment plot over the longitudinal study - Technical Majors

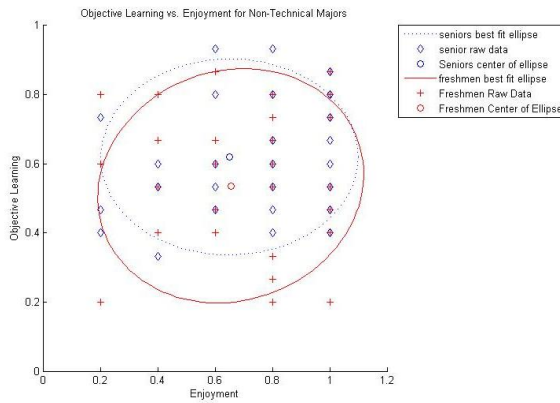The Interaction of Subjective Learning and Enjoyment

Fig. 7. Interaction of objective learning and enjoyment plot over the longitudinal study – Non-Technical Majors

The plot comparing subjective learning versus enjoyment, Fig. 8, reveals conflicting effects of the three-year college experience. First, the students' enjoyment has not changed but is disproportionate to their subjective learning. Second, over the three years, their subjective learning has increased bringing the interaction closer to the 45 degree line. However, the students appear to perceive the task more of a "game" than a learning experience. This perceptive might also explain the third observation. Third, the students have become more sensitive to the delays over the three when reference to the subjective learning and enjoyment interaction. The area of the ellipse has increased, indicating that the students have become more sensitive to delays in terms of the interaction of subjective learning and enjoyment.
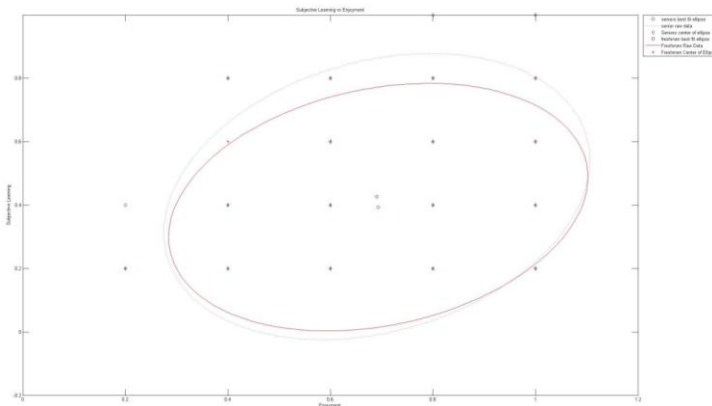

Fig. 8. Interaction of subjective learning and enjoyment plot over the longitudinal study

The difference between students who chose technical majors and those who chose non-technical majors are apparent in Figs. 9 and 10. The centers of all of the ellipses are in the lower right corner, indicating more enjoyment than confidence. Both groups' centers move closer to the 45 degree line. However, the adjustment is very different. Students who chose technical majors have gained more confidence while achieving a small increase in enjoyment. Students who chose non-technical majors demonstrated a small increase in confidence but a greater decline in enjoyment. Given the nature of the task and the differences in their program, the decline in interest in the task is not unexpected.

Second, the area of the ellipse is indicative of the subject's sensitivity to the delay in response on the computer screen in reference to the interaction between subjective learning and enjoyment. Students who chose a technical major experienced no change in their sensitivity to the delays in terms of this interaction. The area changed from 0.5659 to 0.5736. Students who chose a non-technical major had a more pronounced experience. Overall they were less sensitive to the delays and over the three years, the size of their ellipse had decreased from 0.4815 to 0.3915. During the three years of college education, the students who chose a technical major were more sensitive to the delays while the students who chose non-technical majors less affected by the delays and became even less sensitive to the delay in reference to the subjective learning and enjoyment interaction.
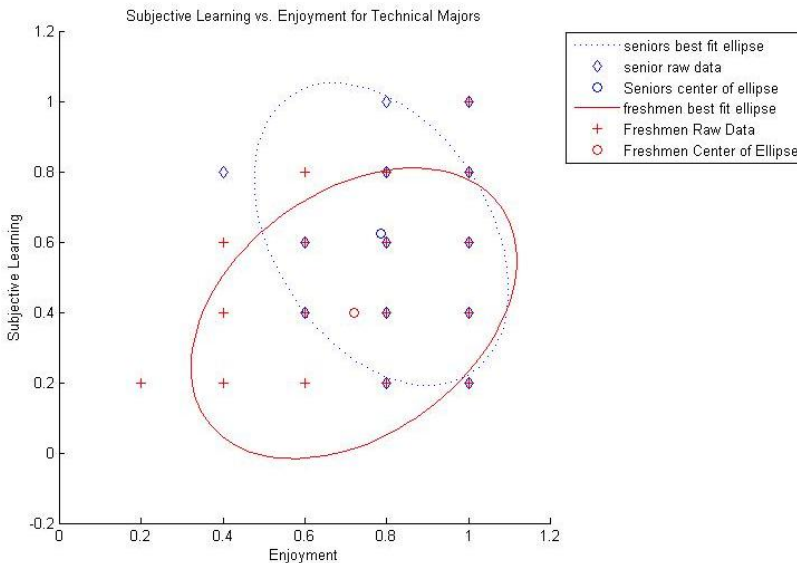

Fig. 9. Interaction of subjective learning and enjoyment plot over the longitudinal study - Technical Majors
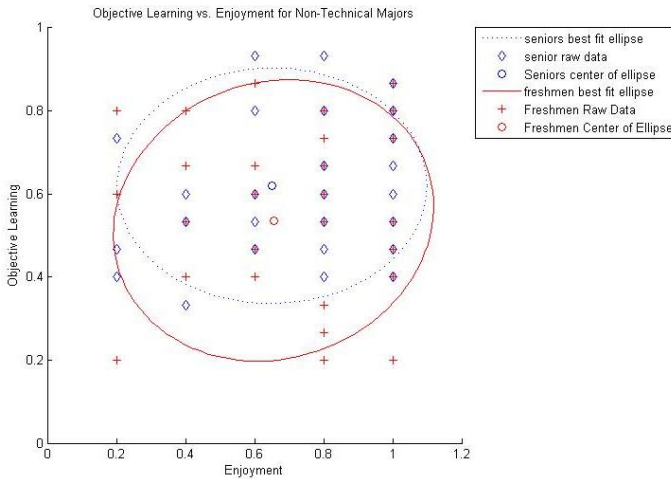
Fig. 10. Interaction of subjective learning and enjoyment plot over the longitudinal study – Non-Technical Majors

4. CONCLUSIONS AND LIMITATIONS

The impact of the computer delays on students change over their college experience. Some changes are observed for all students, but other changes are dependent on the students' choice of major, technical or non-technical. When studying the interaction between objective learning and subjective learning, all the students indicated an increased understanding and expressed over confidence in their abilities. When investigating the interaction between objective learning and enjoyment, the ability to understand the task increased more than the self-report measure for enjoyment bring their response closer to the preferred 45 degree line, and they were less sensitive to the delays. Finally, the investigation of the interaction of subjective learning and enjoyment revealed students' enjoyment is disproportionate to their level of enjoyment. The excess enjoyment over perceived learning might reflect the students' perception of the experimental nature of the task as opposed to a real learning experience.

When the students were separated by their choice of major, technical versus non-technical differences became evident. In reference to the interaction of objective and subjective learning, students who chose a technical major experienced a greater increase in their objective learning when compared to the perceptions. Students chose a non-technical major tended to proportional gains in their objective learning and their perception of its increase. Further, students who chose a technical major had become less sensitive to the delays, while students who chose a non-technical major became more sensitive to the delays. When the interaction between objective learning and enjoyment was studied based on the choice of major, only students who chose non-technical majors

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change their level of enjoyment, which decrease. The differences between students who chose technical majors and those that chose non-technical majors were observed with the interaction of subjective learning and enjoyment. Students who chose technical majors gained more confidence and enjoyment while students who chose non-technical majors had only an increase in confidence and a decline in enjoyment. While students who chose technical majors do not appear to be affected by the delays, students who chose non-technical majors did reduce their sensitivity to delays.

These observations must be considered along with three possible limitations which were inherent in the study. First, as indicated a various points in the discussion of the results, the nature of the task may have an impact on the results. These results could be driven by a task centered on Fourier series, a more familiar task for students choosing a technical major. Further studies must investigate various tasks to determine what is any generalizations can be made across all of e-learning. Second, when considering the interactions of objective learning and subjective learning, further research would be warranted to verify that changes in confidence is caused by the additional online experiences gained during college. Shifts in confidence would have implications about the appropriateness of online experiences for learning various types of tasks. Third, the impact of the enjoyment dimension might reflect the students' perception of the experimental nature of the task as opposed to a real learning experience. The use of online education must be appropriately understood to enhance decisions about its application and its development.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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