The Effectiveness of Innovative Approaches to CS1: Comparing Opinion to Outcome

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Abstract

Handheld computers (Pocket PCs) have been required of all entering CS majors at the University of Minnesota Duluth, since fall semester 2001. To enhance their utilization, customized learning software was created for the devices and integrated into the curriculum through in-class exercises. Student opinion surveys consistently indicated that these hardware and software innovations contributed more toward learning than any other aspect of the course, while lectures were among the least highly regarded learning tools. Examination of student performance data however indicated that highly valuing lectures and high achievement were closely correlated. Other findings suggest that handheld users found interaction with teaching assistants and tutors relatively unimportant. This raises several important issues including how innovative approaches to CS1 might elevate both student performance and opinion, and how innovation and tradition can be made to complement each other in the curriculum.

Keywords: assessment, PDA, handheld computer, educational software, learning theory, visualization.

1 Introduction

Colleges and universities seek to expand the role of technology to open up new avenues for teaching and learning, present new possibilities for research and attract and retain students. One manner in which campuses are increasingly choosing to address this issue is through the establishment of campus-wide wireless networks (Campus Computing Project, 2000). This sets off a chain reaction in which students must own complementary hardware and faculty must respond by devising plans to integrate the technology into their courses. It has been noted that such initiatives may lack the kind of planning that would link learning theory to the new technology (Schneider, 1994). In addition, these major teaching and learning configuration changes oftentimes avoid assessment before the next wave of innovation comes along.

Among the most common implications of campus wireless networks institutions are requirements that students own portable computers to connect to it for web browsing, email or uses within the context of wireless classrooms (Kabara et al, 2000). Recently tablet PCs and handheld devices (primarily Pocket PCs and Palms) have been added to the wireless technology mix along with laptops. All of these platforms are multifunctional in educational settings (Bruce, 2003).

There are several dangers inherent in the process of incorporating technology into teaching and learning environments (Spodak, 2003). First, it is often difficult to discern when a technology is being used incorrectly, or worse, in place of a superior alternative. Second, there is the trap of using technology for technology's sake. Third, there is the danger of having superior tools but poorly designed settings for them (Cuban, 2001). The last concern addresses the potential to proceed without a plan linking learning theory to the capabilities of computing devices.

Current learning theory paradigms focussing on the role of technology stress giving students increasing power to perform real-world tasks (both simple and complex) in non-traditional educational settings using a variety of software tools (Cunningham, 2003). The major goals of technology initiatives should be student empowerment and teaching flexibility (Reigeluth, 2002).

Further insight is provided by O'Connor (1997) who points out that learning often takes place best when students are given the opportunity to use means they are comfortable with. Success is promoted when technology is used in the curriculum to address issues such as: out-of-class experimentation for independent learners, learning cycles (challenging students to explore different modes of learning) and involvement in complex activities. The work of Gagne (1987) underscores the importance of active engagement in this endeavour. Kenimer and Morgan (2003) have demonstrated the value of active learning exercises that involve higher-order learning processes in engineering students. Technology serves as an effective learning aid by enabling the visualization of concepts and the construction of powerful metaphors to support teaching and learning (Wright, et al, 2002). It is important however to find the right place for a technology in the existing instructional modalities of computer science teaching, or create a new ones around it (Shiavi et al, 2002).

2 The UMD iPaq Initiative

An example of the process of reconfiguring curricula to conform to the strengths and weaknesses of a particular technology took place at UMD during the 2001-2002 and 2002-2003 academic years. Over this time period, all incoming freshmen in the fields of computer science, electrical and computer engineering, and other engineering fields were required to purchase a handheld computer (a Compaq iPAQ) with wireless capability. This initiative was put in place for fall semester 2001 and had a broad impact on the college and especially on introductory computer science and computer engineering courses (Carrol, 2003, and Gutierrez, 2003). Nearly all of these students were required to take Computer Science I (CS1) and most chose to enrol in it during their first semester. As a result, a major reconfiguration of CS1 was undertaken to allow students to use their handheld computers in pursuit of educational objectives both in and outside of the classroom (Allert, 2003a).

The initiative planners envisioned opening up new venues for teaching and learning both within and outside of the classroom. Software could be acquired or developed for these devices to gather, store and possibly analyse data, as well as to provide simulations, interaction, reference works or quiz material in easily accessible forms. In addition, students could have access to all course materials (including Microsoft® PowerPoint™ lecture slides) over the Internet. Online polling using the wireless network would provide a further enhancement of the learning environment.

3 CS1 Innovations: Planning and Impact

The first required course for all computer science majors (CS1) at UMD is worth five semester credits. Enrolment varies from 100-300 students depending on the semester. It meets five days per week. Monday, Wednesday and Friday sessions are conducted in a large lecture hall seating up to 400 students. Tuesday and Thursday are devoted to meeting in smaller sections (25 or fewer students) with a graduate teaching assistant. One of these sessions is used as dedicated discussion time, the other is held in a computer lab in which students work on various in-lab exercises and programming projects.

The transitioning of the course to a form in which the wireless network and handheld devices became integral was labour-intensive but ultimately successful. It took place in a series of stages in which the wireless network was put in place and tested while instructional activities were being devised to utilize both the mobile and wireless capabilities of the hardware.

From the standpoint of course development, extensive preparation time was required. Approximately nine months before implementation faculty received handheld computers and began investigation of their potential in the classroom. Several things became immediately apparent. First, the conventional uses of handheld computers, which account for their popularity in the commercial world, were largely irrelevant to the CS1 curriculum. There was no more than incidental intersection between popular handheld applications like personal productivity and time management software and the CS1 course material. It also became apparent that there was no commercially available educational software in this niche. This lack of software continues today.

Even the most broadly applicable programs (such as those for note taking, ebooks, web browsers and email) were of limited use at best. Note taking was cumbersome and slow. A proficient student could manage 15-20 words per minute (far below the capacity required to stay with most CS1 lectures). In addition, the presence of lecture notes on course web pages obviated the need for slavish note taking. EBooks, dealing with computer science topics, were not available but had they been the eBook format has limited capabilities and potential in current forms (Martinez-Unanue et al, 2002). Web browsing also provided less functionality than envisioned. Early versions of the browser did not support Java. Even when viewing plain html web pages the devices often required an inordinate amount of scrolling both horizontally and vertically to capture page contents, context and meaning. Email applications were not attractive for the same reasons although for short emails without attachments they were useful. Overall, there was very limited potential for developing course content delivery along these lines (Deneen and Allert, 2003).

The impact of the realization that integration of handheld computers into CS1 would not be automatic forced the instructor to consider major changes in course methods and materials. Ultimately, the challenge of integration was met by going back to the course objectives and reconsidering how they could be met more efficiently and effectively with the new learning tools. This necessitated an even deeper reconsideration of how students learn computer science and an identification of those aspects of the current course that could be improved. This reflective process identified areas in which the current approach was not optimal. The handheld technology was targeted for the improvement of these areas rather than use in areas of the course in which current methods of instruction seemed to be working well already. This limited course redesign to some extent.

The weak spot in the course was identified as the weekly discussion sections, in which teaching assistants of varying capabilities conducted teaching sessions of varying quality. This was the point at which the learning theory emphasis on empowering students through active learning techniques and the provision of new venues for learning was considered. The former discussion sections were replaced by formalized sessions in which students were engaged in simulations, animations, interactive exercises, quizzes and other forms of involvement with course concepts through software downloadable to their handheld computers from the wireless network. Short written exercises accompanied the applications to insure that students interacted with each concept area covered by the software. Teaching assistants worked within the parameters of the software using the accompanying exercises as a framework for teaching. Students took the software away with them on their handheld computers enabling them to use these tools as study aids and reference tools at their leisure.

To facilitate the new discussion sections software was written to serve their needs. Overall 80 small programs were constructed to illustrate specific issues, techniques, process and methods. These were then bundled into 17 applications, each addressing one key conceptual aspect of the course (control structures, searching, sorting, strings, analysis, etc.). Downloadable executable versions of the software were placed on the course web page (Allert, 2003b). The handheld devices and their accompanying software became companion technology innovations for the teaching of CS. Each week's session covered a specific key concept. Rather than duplicating what was presented on this concept in lecture, the software was built to answer questions students most commonly asked in class and to allow them to interact with archetypal problem examples. These programs became the new backbone of CS1. Students used them frequently and often passed them around via infra-red file transfer to one another. The redesign of this portion of the course seemed to work well and transformed this portion of the course from an instructional outlier into an event of central importance. It also provided frequent and significant use of the handheld computers students had been required to purchase.

The downloadable course software addressed critical course content issues, used the wireless network, and exposed an important aspect of the handheld initiative that had been previously unrecognized by decoupling the concepts of mobile and wireless computing. Students were seen using the software in much the same way as they would play a video game (while standing in line, waiting for a bus, sitting in the hallway outside of class, in the cafeteria, etc.) most of this while outside of wireless network range. The availability of this 'companion technology' (software and handheld computer) had the effect of producing a class dynamic that was very different from the traditional CS1 model.

By the second year of the program the initiative had expanded to include laptop computers. The course software was revised to provide an interactive version that could run both over a web browser or be downloaded to run on the student's PC. The following spring (2003) use of the software tools was expanded out from discussion sections into the large lectures, providing a method of teaching that was as graphically interesting as PowerPoint™ but more dynamic.

The net effect was that CS1 was transformed from both the top down and the bottom up. The top-down transformation involved the construction of a learning model that covered each aspect of the core material in a variety of ways, including more active learning opportunities. The bottom-up transformation involved the new culture of learning that evolved among students who were able to use the interactive software in formerly non-instructional settings and transform those settings into learning events in much the same way that a handheld video game transforms a setting (like a bus stop or park bench) into a game event location.

4 Assessment

Student opinion surveys were taken throughout the first semester of this initiative (fall 2001) and subsequently the following year (fall 2002). These investigations delved in to issues such as what software was being used and how often, how were the devices being employed in other classes, and which of the overall course components did students feel were most helpful.

The cost of the initiative was not popular with students, although many liked the devices. Each unit cost $800 USD. This was a new mandatory fee imposed by the College. With this in mind, it was all the more remarkable when survey results showed that students rated the handheld software as contributing to their learning more than any other component of the course (Table 1). The surveys were taken during mandatory class sessions. Response rates were 87% for 2001 and 89% for 2002.

Learning Component	***Average Rank 2001 (n=141)***	***Average Rank 2001 (n=161)***
Concept software	*3.24*	*2.99*
Textbook	*3.15*	*2.63*
In-lab Programs	*2.95*	*2.86*
Teaching Assistants	*2.88*	*2.82*
Large Lectures	*2.73*	*2.73*

Table 1. "How helpful to you were the following…?" (1=No help to 4=Very helpful)

These findings were taken to indicate that students could separate their distaste for the imposed handheld technology initiative from the issue of learning. The concept software clearly had merit. Nevertheless, the most disturbing aspect of the results seems to be the low regard students had for lecture. Given that most classroom activity was of the large lecture format this finding may indicate that this portion of the course should be redesigned next.

Student opinion surveys were expanded in the second year to also assess variables such as 'prior knowledge of the subject', 'use of the Tutoring Center', 'use of teaching assistant (TA) office hours' and other factors. Surveys were then linked to student performance indicators in the form of total points for the semester. In addition, the entire class could now be subdivided for assessment purposes into those with handheld computers (n=104), those with laptop computers (n=20) and those who were not covered by the initiative (n=40). The first two groups were composed exclusively of incoming freshmen in the majors subject to the wireless initiative. The third group was made up of students (from freshmen to graduate status) primarily in fields outside of computer science and the engineering disciplines. This group was very different from the first two.

At the end of the semester analyses were carried out to test for a link between performance measures and student opinions on the value of each course learning component. This resulted in the production of a series of relationship matrices in which the class as a whole, and the largest subgroup (handheld computer users) could be assessed with regard to opinion and outcome variables. The size of the laptop subgroup was too small to profitably undergo this procedure and the third group was so demographically different that statistical comparisons could not be meaningfully performed.

The results for all students in the fall 2002 group (n=161) are shown in cross-tabulation Table 2. The results for the handheld computer user component of that population (n=101) are shown in cross-tabulation Table 3. All variables were approximately normally distributed. Values recorded in each cell represent the Chi square (χ^2) level of significance. χ^2 is a nonparametric test of association for ordinal variables (Healy, 1993). It is based on the squared difference between the expected and observed frequencies in one cell of a bivariate table divided by the expected frequency for that cell. These differences are then summed and the resulting value used to compute a probability value along a χ^2 distribution based on the degrees of freedom in the table. The probability value from the χ^2 distribution ranges from 0-1 where 0.00 indicates association dependence and 1.00 indicates association independence. The null hypothesis is independence of association between the two variables and was rejected in this case when probabilities dipped below the .05 level of significance (these are recorded in the shaded regions of the triangular matrix (Tables 2 and 3). A secondary probability levels (from the 0.05 up to the .10 level of significance) are marked in boldface type on these tables. The level of significance is the probability that the bivariate configuration could have occurred by chance alone. Total points were assigned into ordinal categories using natural breaks in the grading distribution to produce an ordinal variable, with similar category frequencies, that could be related to the ordinal opinion results.

	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
2	**0.00**							
3	**0.07**	0.17						
4	**0.02**	**0.00**	**0.00**					
5	0.25	0.40	0.10	0.53				
6	0.92	**0.00**	0.91	0.13	0.30			
7	0.63	0.29	0.24	**0.08**	0.63	0.23		
8	0.26	**0.00**	**0.05**	**0.03**	0.15	**0.00**	**0.00**	
9	0.66	0.69	0.23	**0.02**	0.18	0.93	**0.00**	0.17

Table 2. Association probabilities (p) resulting from c^2 analysis of crosstabulation tables for nine ordinal variables across all students. Shaded areas denote p < .05, boldface .05 <= p < .10)

<u>Key to row and column integers</u>

1= Total Points

2= Amount learned (1=nothing to 4=very much)

3= Concept exercises (1=not helpful to 4=very helpful)

4= Lectures (1=not helpful to 4=very helpful)

5= Textbook (1=not helpful to 4=very helpful)

6= In-lab programs (1=not helpful to 4=very helpful)

7= TA office hours (1=not helpful to 4=very helpful)

8= TA classroom (1=not helpful to 4=very helpful)

9= Tutoring (1=not helpful to 4=very helpful)

Table 3 is a breakdown of the correlations among those students who were handheld computer users.

	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
2	**0.00**							
3	0.19	**0.03**						
4	**0.00**	**0.00**	**0.01**					
5	0.86	**0.04**	0.87	0.34				
6	**0.06**	**0.01**	**0.09**	**0.04**	0.44			
7	0.57	0.52	**0.06**	0.35	0.46	0.10		
8	0.12	0.12	**0.00**	**0.02**	0.69	0.11	**0.01**	
9	0.59	0.16	**0.02**	**0.05**	0.17	0.62	**0.00**	**0.09**

Table 3. Association probabilities (p) resulting from c^2 analysis of crosstabulation tables for nine ordinal variables across all handheld students. Shaded areas denote p < .05, boldface .05 <= p < .10)
Row and column legends are the same as Table 2.

The nine key variables can further be classified into activity ratings (lecture, exercises, in-labs, TA office hours, TA classroom, and use of the tutoring center), performance outcome (total points) and performance opinion (amount learned). Both 'total points' and 'amount learned' may be treated as dependent variables while the others are knowledge delivery vehicles constituting independent variables, although the χ^2 test need not distinguish. It should be noted that the two dependent variables in this approach (total points and amount learned) were strongly correlated overall and within the handheld users (p =.000 for both). This may indicate that students were keenly aware of their achievement potential in the class and that 'amount learned' is similar to a surrogate for 'total points'. This survey was conducted in week 14 of a 15 week semester so it is conceivable that students (who had already completed 75% of the graded coursework) would have a good idea of what their final grade outcome would be. Students were aware of their total point ranking as it was posted weekly on the course web site.

Table 4 depicts the independent variables from Table 1 that were significant below .05 in relation to the outcome variable 'total points' and opinion variable 'amount learned'. Whereas the χ^2 analysis was used to detect correlations between variables thereby disclosing relationships that were unlikely to be the result of chance, gamma (G) indicates the direction and degree of association in these relationships. Gamma ranges from -1 to 1 where -1 and 1 are perfect relationships and 0 is no association. In this case, a positive value for gamma indicates positive relationship such that increases in one variable (like total points) are associated with corresponding increases in the other variable (such as 'How helpful were lectures?').

Gamma is a proportional reduction of error (PRE) measure which quantifies the reduction in prediction error when knowledge of one variable is used to predict the other (Healy, 1993). The cells of Table 4 and Table 6 indicate the gamma along with the n for each of the relationships identified in Tables 2 and 3 as statistically significant below the .05 level. In cases where the χ^2 probability was above the significance level cut-off gamma was not computed. These relationships are marked as NA (or not applicable for gamma analysis). Among the variables whose relationship to total points was not statistically significant at the 0.05 level and marked NA were opinions about the usefulness of in-lab programs and teaching assistant classes. The other non-significant relationships were the concept exercises, textbook, TA office hours and tutoring, although concept exercises for this group were close (0.07) to the significance cut-off level of 0.05 in Table 2). A significance cut-off level of .10 would include concept exercises. The results indicate that among the class as a whole outcome was tied primarily to lecture and secondarily to concept exercises.

The interesting aspect of Table 4 is that the amount a student learned (an opinion) was positively associated with opinions related to several key learning events (lectures, in-labs and the TAs) while actual performance (total points) was only associated with lectures (again a positive predictive relationship).

Class Activity	Total Points gamma, (n)	Amount Learned gamma, (n)
Lecture	.332 (152)	.466 (154)
In-labs	NA	.470 (154)
TA class	NA	.383 (156)

Table 4. Direction and proportional reduction of error (gamma) for associations with levels of significance < .05. for the variables outcome (Total Points) and opinion (Amount Learned) for all CS1 students (fall 2002).

Considering the low average ranking lectures had been given relative to the concept visualization software and virtually every other component of the course in the initial summary tables (Table 1) this result was striking. Further inspection of the bivariate distribution table indicated that lectures were rated highly by those in the top rank of total points and low by those in the lowest total point category thereby establishing the trend. Students in middle point categories tended to rate the lectures more evenly across all categories but with the heaviest frequencies on the low end overall. Both the diagonal trend and the weight toward the bottom of the lecture opinion scale are evident in Table 5.

Lectures -> Points	Not Helpful	Helpful	Very Helpful	Totals
Lowest	*23*	*9*	*6*	**38**
Third	*18*	*15*	*7*	**40**
Second	*19*	*12*	*10*	**41**
Highest	*8*	*9*	*16*	**33**
Totals	**68**	**45**	**39**	**152**

Table 5. Cross-tabulation table of Total Point categories by Lecture (How helpful?)

Among the handheld computer users the correlation configuration changed somewhat with regard to their opinions (the concept software emerged as a significant correlate) but was identical to Table 4 with only lectures significantly correlated with outcome (total points). Table 6 shows the relationships with statistically significant correlations ($p < .05$) for these students. It depicts the variables from Table 2 that were significant below .05 in relation to the outcome variable 'total points' and opinion variable 'amount learned'.

Several opinion variables were positively associated with the perception of amount learned including the concept exercises, the textbook, in lab programs and lectures.

Class Activity	Total Points gamma, (n)	Amount Learned gamma, (n)
Lecture	.507 (93)	.429 (95)
Concept exercises	NA	.304 (101)
Textbook	NA	.315 (100)
In-labs	NA	.502 (98)

Table 6. Direction and proportional reduction of error (gamma) for associations with levels of significance < .05. for the variables outcome (Total Points) and opinion (Amount Learned) for handheld using CS1 students (fall 2002).

Among the variables whose relationship was not statistically significant at the 0.05 level with regard to total points (marked NA) were opinions about the usefulness of the concept exercises and textbook. The other non-significant relationships were the, TA office hours, TA office hours and peer tutoring, although in-lab programs for this group were close (0.06) to the significance cut-off level of 0.05 in Table 2). A significance cut-off level of .10 would include in-labs. The results indicate that among handheld users outcome was tied primarily to lecture and secondarily to the active learning acquired through the in-lab programming assignments. The positive association of lecture is again the only one tied to actual performance (total points) at the .05 level.

The conclusions that can be drawn from Tables 4 and 6 are that overall the only variable significantly related to performance was lecture and this was a positive association such that the more highly a student rated the value of lectures the higher that persons total points were likely to be. This was true of the class as a whole and of that subset consisting of handheld computer users.

If we consider the secondary relationship variables for total points we can augment these conclusions with secondary factors whose strength of correlation is significant below .10. There were only two of these related to total points. For the class as a whole the concept software was a secondary factor ($p = 0.07$) while in-lab programming exercises were decidedly not ($p = 0.92$). For the handheld users the in-lab exercises emerged as secondary factors (p=0.06) while the concept software was of less importance (p=0.19).

Looking further at the secondary factors discloses perhaps the most important relationship of all however. For the class as a whole, the relationship of concept software to performance was a negative association (gamma = -.204). This is indicative of a bivariate distribution such that the more highly a student rated the software the less likely s/he was to be among the top of the class in total points, this despite the overall ranking of the software as the most helpful learning component in the course (Table 1).

5 Summary and Conclusions

The introduction of handheld computers, laptops, a wireless network and concept visualization software revolutionized the manner in which CS1 was taught at the University of Minnesota Duluth from the fall of 2001 through the spring of 2003. Student opinion surveys consistently indicated two trends. First, students ranked the innovative concept visualization software as the most helpful aspect of the course. Similarly, students ranked lectures as among the least helpful aspects of the course.

The implication is that there is great potential for the future success and expansion of high-tech innovations such as wireless network and handheld or laptop computing as an alternative to lecture formats. The static aspect of large lectures seems to remain unappealing whether it is based on chalk talks, overhead transparencies or PowerPoint™ and the Internet.

However, averaged student opinions are not always what they seem. Correlations of these same student opinions with actual performance data show clearly that lectures are positively related to outcome, more so than any other aspect of the course. What are we to make of these seemingly contradictory findings?

Several conclusions are evident from the analysis above. First, high achieving students valued lecture highly while low achievers did not. Overall, most students do not value lecture highly. Second, as a predictive measure for outcome (total points), a student's ranking of lecture was the single best indicator. It would seem that among students who did not excel the course material was perceived as more inaccessible in lecture format than other methods. This produced the low overall opinion ranking and high correlation with performance.

The role of the concept visualization software is an ambiguous one. Why was it repeatedly ranked as the most influential learning component of the course? There could be several different conclusions here. One interpretation is that the new technology produced a "halo effect" in which students felt they were aided best by the most visually attractive aspect of the course. The experience gained from this initiative shows that concept visualization software is well received by students, especially if it runs on multiple platforms and can be used with mobile devices .

The appeal of visualization software may be a mixed blessing. Interaction with a simulation is an easier mode of learning than actual programming because it is interaction with an abstraction. Concept software mastery can be relied upon too heavily, to the extent that higher-order learning tools are devalued (such as actual engagement with the computer writing and debugging code). The secondary correlates may betray that this has happened in this study. Among the handheld users the secondary correlate to lecture was involvement in in-lab programming assignments, suggesting an appreciation for the value of hands-on coding. Among the class as a whole the secondary correlate to lecture was involvement with the concept visualization software and decidedly not with the in-lab programming. This indicates that many non-CS students are gravitating toward the lower order components as their primary learning tools. The overall negative association between the concept software tools and total points may be indicative of the adverse effects of making lower order learning opportunities too central to the course. This issue raises again the need for more inquiry into learning style issues in computer science.

Lectures serve good students well and can function as effective learning events for many. Other students are less attracted to it and more attracted to new technology. The experience gained from this initiative has stimulated the experimentation with more dynamic forms of small class discussion and large lectures through the introduction of concept visualization software in which simulations, animations, quizzes and other forms of interaction can take place. The hope is that we may not have to decide which modality is best, but discern their proper roles, levels of engagement and proportional presence to make effective new inroads into computer science education for all students.

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