Comparative Analysis of Palm and Wearable Computers for Participatory Simulations.

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Introduction

Meaning and Goals of Inquiry-Based Learning in Science Education

Much of the thinking in science education focuses on the need to make science learning more like the practice of science. Calls for inquiry-based learning, developing skills for systems thinking, harnessing the tools and technologies of scientific practice, and creating scientific investigations that reflect current understanding, are all components of this focus. Many reformers argue that science education should—like science practice—consist of activities such as framing problems, devising experiments, collecting data, and refining hypotheses (National Committee on Science Education Standards and Assessment, 1996; Project 2061, 1993).

At the same time, studies in cognitive science over the last few decades have revealed important information about how people effectively think and learn which has had an enormous impact on both educational theory and practice. Social constructivism and its corollaries in situative theory and communities of practice suggest that learning should be constructive, collaborative, interactive and contextualized (Rochelle, 2000) rather than the didactic, transmissive modes of instruction based on a teacher-centered pedagogy found in more traditional classroom methods.

Furthermore, several education theorists (Bereiter, 2002; Dede, 2000) and other long-standing advocates of education (Drucker, 1994; 1999) have focused on the importance of structuring experiences in classrooms that mirror the complexity of our present society. The shift from an industrial-based to an information-based economy has created a demand for students with a new set of skills. Traditional school curricula and activities are poorly adapted to helping students gain proficiency in working with conceptual artifacts where collaborating effectively, working with incomplete information, adapting to changing conditions, managing complex decision-making, and creating and sharing knowledge are thought to be critical components of a healthy, functioning and productive society.

As we rethink the educational domain and in particular the science curriculum, many people are also calling for a tighter integration between technology and the disciplines that children study in school (Linn & Hsi, 2000; Means, 1998; Means & Golan, 1998; Shaw, 1997). Rather than viewing computers as add-ons to the curriculum, researchers and educators increasingly strive for computers to be embedded and integral to classroom learning experiences from the outset. This move toward technology-integration fits well with the desire to support learning through authentic science practice. Like scientists, students can use computers to support and enable sophisticated experimental design, execution, and analysis. Using new modeling tools, students can collaboratively frame and solve problems, engage in iterative investigation, and modify their models based on emergent and evolved understanding. Teaching students to use computers for investigating problems and designing solutions can improve their understanding of technological tools as well as their understanding of the process and content of science.

In addition to enabling more authentic science-like problem-solving, recent educational computer-based technologies have offered promising lines of research that promote the goals articulated in arguments both for social constructivist learning and the development of skills required to operate in a knowledge-based economy (see Rochelle et al., 2000 for a compendium of projects). In our research program, we have been interested in combining all three of these aims for curricular reform in school science by developing innovative and progressive handheld and wearable computational learning tools. This paper reports on one such line of research in which the learning outcomes of two distinct technological platforms are compared using the same pedagogical strategy of Participatory Simulations.

Participatory Simulations and Wearable Thinking Tag Technology

In their original form, Participatory Simulations used small custom wearable computers called "Thinking Tags", or "Badges" (Figure 1) to engage participants in simulations that enable inquiry and experimentation (Colella, 2000).

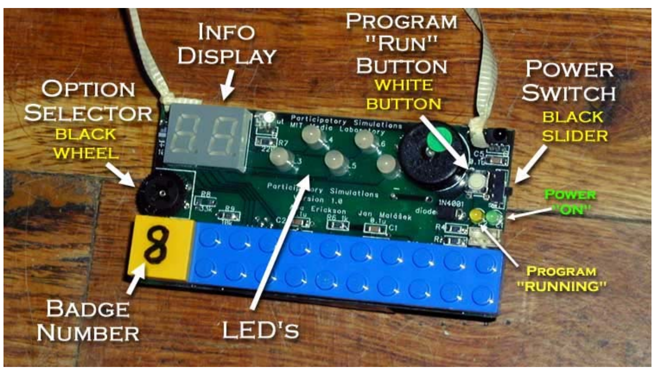

Figure 1 – A "Thinking Tag"

In these simulations each participant wears one of the small computers, which allows them to become agents in the simulation (Colella, 2000; 2002). Unlike computer simulations where phenomena are observed on a computer screen, Participatory Simulations allow students to act out the simulation themselves. Students do not just watch the simulation, they directly participate. After experiencing a simulation, students discuss their findings and try to understand how the system works. The Thinking Tags themselves are about the size of a name tag, and is little more than a circuit board with an inexpensive processor, a two-digit LED display, a series of five LEDs that can be red, green or amber, a speaker, two input devices – a dial and two buttons, and most importantly the ability to send and receive IR communication between devices. The Tags are decorated with Legos for identification and to make them fun. They can be programmed to represent simulated characteristics of the wearer such as infection by a virus which has been used to explore complex epidemiological factors involved in the spread of disease. Colella (2000; 2002) for example found that a participatory simulation of an epidemic was highly motivating to a class of "underperforming" high school students in an urban school. The students engaged in inquiry, collaboratively designed experiments, analyzed data, and participated in authentic scientific methodology.

Over the last few years, we have also investigated how Thinking Tags can help us understand collaborative learning processes in pre-school students all the way to academic conference participants (Andrews et al., 2003; MacKinnon et al., 2002; Klopfer & Woodruff., 2002; Yoon & Woodruff; 2003). Through a variety of simulation topics such as dental hygiene, genetic inheritance and genetic engineering, we have found that the learning benefits accord in four main categories: i.) Motivation--students want to participate, and find that the technology pushes them to be involved in the system; ii.) Support for Collaboration--interactions between students in the game are critical to the outcome, and a successful run is dependent on the interactive discussion of the class; iii.) Engagement--most students, regardless of gender or background, find the technology and the simulation compelling, and readily participate in the inquiry process; and iv) Excitement--students enjoy learning, are satisfied with their experience, and want to play more.

Participatory Simulations and Handheld Palm Technology

While additional simulations have been developed using Thinking Tag technology for studying predator-prey systems, market economies, and the evolution of cooperation, several limitations of the platform which include high cost, low durability, and difficulties in programming have prevented us from simply manufacturing and distributing them.

At the same time PDAs such as the Palm are becoming more ubiquitous in the classroom (Roschelle & Pea, 2001; Soloway et al., 1999; Tinker & Kracjik, 2001). Many applications are being built for use on the Palm by K-12 students including Probeware for sampling scientific data (Tinker & Kracjik, 2001) graphing and computational tools for enhancing quantitative understanding, and concept mapping and information gathering utilities for help students in constructing knowledge. Given the growing presence of this platform in the classroom, the inherent characteristics of this technology – including their size and IR communication abilities, and the learning benefits of Participatory Simulations, we decided to port many of the existing Thinking Tag games to the Palm.

The Hi-CE group at the University of Michigan (Soloway et al., 2001) have already developed a version of the virus game on the Palm entitled “Cooties”. Cooties has been used extensively in the Detroit Public Schools at the Middle School level, with reported success. But there has yet to be a study explicitly comparing the Palms to the Thinking Tags for the purposes of determining whether the two platforms are equally capable of motivating and exciting students to engage in these simulations.

Palm vs. Tag Study

The purpose of this pilot study was to gain some initial information on whether the Palm Participatory Simulations were capable of reproducing the enthusiasm, personal involvement, and desire to study these systems generated by the Tags. While the Palm has many advantages, including display screens and interface, they don’t have the bright lights, playful look, or simplicity of the Tags. This study was conducted to see whether the Palms could capture the desired elements of game play from the Thinking Tag platform. Specifically we were interested in evaluating indicators of engagement and excitement about learning – some of the components determined to be critical to the success of the Tag games. Hence in this study we investigated factors such as level of engagement in the activity, motivation to participate, technology usability, and self assessments of learning. We leave it to future studies to specifically determine content learning based on the activities.

The questions that we sought to answer from the study were:

1. How do the Palms versus the Tags provide for the motivation, support for collaboration, engagement and excitement that have been found to be crucial in earlier studies?
2. What are the differences in usability and technological facility between the Palms and the Tags?
3. What other affordances can Palm Participatory Simulations bring to the classroom?

Methodology, Participants and Data Sources

Virus and Live Long and Prosper

This study employed two the simulations – Virus, an epidemiological simulation, and Live Long and Prosper (LLAP), a simulation of Mendelian genetic inheritance. The Virus game was essentially similar to Collela (2000). In this game one person, unbeknownst to them, starts out harboring a virus. People are told that they should meet (by beaming infrared to other players) as many people as possible without getting sick, though they are not told how one gets sick. The game keeps track of the number of unique people that they meet. At some point, one person's lights turn red, indicating that they are sick. Many other players' lights turn red in rapid succession, showing that they too are sick. Some players, however, do not get sick. The students can play the game again, and the focus becomes figuring out how the system works. Who starts the virus? How does it get passed? Why don't some people get sick? Students collaboratively design and conduct experiments that inherently involve the entire class. The Palm version of the game included the same elements as the Tag game, though it did track the names of the people that were met, and provided a graphic on the screen indicating whether someone was healthy or sick. Since there were no lights that could be seen from afar on the Palms, when someone got sick an alarm went off and they were required to flip a two-sided (red and green) card worn around their necks from green to red when they got sick (of note were that after being given the Palms and these two sided cards, which simply consisted of a red and green index card stuck together, students often inquired how the cards worked, assuming that there was something electronic about them). For a more detailed description of the Virus game and the associated classroom dynamics see Colella (2000).

Live Long and Prosper, is a genetics Participatory Simulation. Players take the role of an organism with a simple genome (between 1 and 8 genes) that is represented on their screens. Players quickly age and must produce offspring to survive. Players get points for surviving and reproducing, which is important for motivating the initial entry into the game. The importance of the point structure quickly fades as the true nature of the game becomes trying to figure out what the genes stand for. In the handheld version, five genes are displayed graphically on the screen, while the Thinking Tag game shows the genes represented as colored lights. The genes are randomly assigned and each one determines a specific trait that can either have a genotype be homozygous dominant, heterozygous, or homozygous recessive at that position. This represented on the Palms as dotted, striped or clear, and on the Tags as red, blinking, or green respectively.

Figure 2. Two palms shown playing Live Long and Prosper.

Players in this game are told to live as long as possible and reproduce. Their ability to survive and reproduce is influenced by their genomes so figuring out what the genes stand for is critical in survival. Players mate with other players by lining up their Palms or Tags and exchanging genomes through IR. One can think of these organisms as breeding in discrete generations. After the parents reproduce once, they die. When a player dies, they receive an indication that tells them their age of death, and score. On the Palms they have the option of looking at the data from this round (the matings and resulting offspring), or starting a new game themselves. On the badges they must be quickly reinitialized by the instructor (takes a few seconds).

The genetics simulation focuses on basic genetics concepts of dominance /recessiveness relationships found to be a common domain of misconceptions by introductory biology students (Heim, 1991; Lewis & Robinson, 2000), understanding homozygous and heterozygous genotypes and phenotypes and genetics crosses. The simulation also is designed to help students develop scientific inquiry skills. The underlying goal of this game is to have students determine the traits that each gene codes for, by doing genetic matings.

Both the virus and genetics games have similar classroom dynamics. And in this study, careful attention was paid to running the activities with the same organization, including timing of group and individual work, directed instruction, and structure of discussion. As an example of the classroom dynamics, a typical genetics game went as follows.

On the first day, the facilitator introduces participants to the genetics simulation. Five genes are drawn on the board, similar to the graphical representations displayed in the game. Students are told that the genes represented a genotype of either homozygous dominant, heterozygous, or homozygous recessive but that they need to determine how the symbols map onto these characteristics. The facilitator explains to the students that each gene codes for a specific trait but does not provide any information on the specific traits. Each student is given a Palm or Tag and specific instructions on how to start and run the simulation. The students are then given the opportunity to explore the simulation for themselves.

The game begins and students walk around the classroom finding others to mate with. After about ten minutes of participating in the first game, students are stopped from playing and the facilitator leads the class discussion related to what the students had experienced. The facilitator writes all of the information given to him by students on the board. Before playing the second round, the facilitator provides the students with a generic data-recording sheet with three columns (Parent 1, Parent 2, and Result) and encourages the students to record results.

The second day begins with a discussion led by the facilitator aimed at soliciting what the students had discovered about the simulation on the previous day. After this discussion, students play one game for approximately 10 minutes followed by the final discussion of the activity, which lasts the rest of the period.

Data collection

Two high schools (one public N=71 and one private N=117) in the Boston metropolitan area were selected for the Live Long and Prosper, while one (private N=82) middle school was selected for the Virus game. The schools were selected on the basis of their willingness to commit many sections of their biology classes (for the high schools) or science classes (for the middle schools) to the project. In most cases the games were played across two 50 minute periods in consecutive weeks. In a few cases the games were instead played in back-to-back 50 minute periods. By chance, one of the middle school classes had extra time in their schedules, so they had the opportunity to play both versions of the game virus game, and served to provide direct comparisons between the two platforms.

During this first phase of testing the focus was on the relative abilities of the two media to capture the social dynamics, interactivity and their ability to generate excitement about and investment in the experimental design and investigation of the systems. As such, the data that was collected focused on these dynamics. The data collected included pre and post surveys, video analysis of the classes, individual behavioral observations, and real-time summaries of class strategies. In this analysis we focus on the following:

- Pre-survey questionnaires on student attitudes and experiences concerning computers, electronic games, and educational technologies.

- Post-survey questionnaires on students' self assessments of their learning, attitudes towards the simulation, feedback on the technology, and follow-up to several of the pre-survey questions.
- Snapshots of individual behaviors during the games that were captured using Sean Brophy's VaNTH Observation System (VOS). Using a palm pilot running VOS, a researcher followed individual students for 5-10 minutes each tracking which of 12 selected behaviors they were doing at all times. Selected behaviors were those typical observed during pilot studies including beaming data to other students, analyzing data, talking, walking around, and taking notes. Summaries were taken noting the total time students spent in the different activities.

Results

The pre-survey data revealed some interesting trends that were present across all schools and groups. We provide this analysis to provide a baseline for the use of technology and games in the student population's normal life in and out of school. We wanted to establish a starting point for their patterns and attitudes. Students were asked to rate their agreement with a series of statements and their patterns of use relating to technology, simulations, and games in the classroom. Frequency of use was rated on a scale of 1 (used at least weekly) to 3 (used less than once a month). Interest was rated on a scale of 1 (little) to 5 (a lot). All statistics are corrected for multiple comparisons.

Student Backgrounds and Characteristics

Table 1 shows that the students in this study indicated that they used computers a lot at home and at school, but did not use them often in science class or to conduct science research. Of importance to this study was the low usage of Palm Pilots and only moderate use of handheld and online games, showing that these students were not jaded by these new technologies. While students did not feel like that had much game playing ability, they had high interest in games. These results show a population with strong interest and little experience in using technology or games in their science classes.

Despite recent evidence that electronic gaming is increasing in both boys and girls, there is still often concern when introducing games into the classroom of the potential for biasing the experience towards boys. We further analyzed the initial preferences towards technologies and gaming to identify differences between male and female responses, to see whether these differences might impact game play. There were no significant differences between genders on computer use, PDA use or technology attitudes. There were, however, statistically significant gender differences in interest in and use of games. Females used handheld games (mean = 2.65 vs. 2.22) and online games (mean = 2.45 vs. 2.05) less frequently than males, and rated their ability (mean = 1.74 vs. 2.38) and interest (mean = 3.18 vs. 4.05) in games lower than males as well. The questions that we asked of the students were quite generic, and might be associated with particular types of games that have traditionally appealed less to girls. We will later examine whether these initial preferences affected their engagement or interest in this particular game.

	Mean	Std. Error Mean
Play electronic handheld games	2.43	.046
Play collaborative games online	2.24	.051
Use a PDA such as a Palm Pilot	2.78	.034
Use a computer at home	1.03	.012
Use a computer at school	1.48	.044
Use a computer in your science class	2.84	.024
Use a computer to conduct science research	2.49	.038
Ability at games	2.07	.043
Interest at Games	3.64	.065

Table 1 – Student usage and interest patterns in technologies and games.

Table 2 shows that the students had largely positive attitudes towards the potential of technology in the classroom, indicating that they thought games should be used for learning, and that computer simulations and electronic games had a positive impact on science learning. At the same time there was evidence that these students didn't think technology was used enough in their own science classes. They strongly agreed with the statement that computers should be used more in their science classes, and that technology wasn't that difficult to integrate (mean = 2.38), showing that they did not see the barriers to integrating more technology into their classes.

	Mean	Std. Error Mean
I think that computers should be used more within our science classroom.	3.83	.053
Electronic games should not be used for learning.	2.11	.062
Computer simulations should be used for teaching.	3.71	.050
You can learn a lot about science from electronic games.	3.45	.054

Table 2 – Student attitudes about computers and games in the classroom

Comparisons of Motivation, Collaboration, Engagement and Excitement

All of the classes were able to conduct at least three rounds of experiments, and discover at least half of the mechanisms at work in the respective games. Post-surveys assessed student attitudes and self-assessments of the experience, rating their agreement on a scale of 1 (disagree) to 5 (agree) with a series of statements.

Table 3 shows that students viewed this as a highly enjoyable and productive experience. Students felt like they had fun, and rated their learning about content (genetics or epidemics), technology and experimental design highly. They also expressed a strong interest in playing another Participatory Simulation game. These responses support that the technology was uniformly able to promote motivation, engagement and excitement with these students. In comparing the responses of males and females the only motivational and learning differences was that males thought that they learned slightly more about experimental design than did females (mean = 3.80 vs. 3.45). The differences in initial tendencies towards game play and technology between males and females then did not have an impact on this particular game.

	Mean	Std. Error Mean
I thought the technology was fun.	4.39	.045
I thought the technology helped me learn.	3.95	.053
I feel like I learned something about genetics/epidemics.	3.64	.065

I feel like I learned something about technology.	3.72	.056
I feel like I learned something about experimental design.	3.64	.059
I would want to do another one of these activities.	4.31	.051

Table 3 – Student reactions to the participatory simulations.

This experience showed evidence in enhancing the students' own desire to see increases in the use of computers in their classes. Students felt more strongly after playing the games that they could learn a lot about science from games (mean =3.99 vs. 3.45), and they also felt that computers should be used more in the classroom (mean = 4.03 vs. 3.85). Again these differences both show that the experience was quite positive for the students, as they would like to see similar opportunities with technology and games integrated into their classes elsewhere.

The behavioral data that we collected showed extremely high variability across individuals. As such, we have only provided limited analysis of this data (the Virus game data was so highly variable that we cannot comfortably rank the top behaviors). Across both platforms, the most highly prevalent behaviors for Live Long and Prosper are:

1. Beaming
2. Talking
3. Manipulating data
4. Walking

These activities show that the students were involved in a mix of technological, social and analytical activities. But of special significance are that the top two activities are socially collaborative strategies. This is important not only because evidence shows that promoting collaboration within the classroom is a crucial learning strategy, but also because it is likely to be related to the engagement of females in the activity – providing for collaborative game play.

Comparisons of Technology

Contradicting our conjectures, Table 4 shows that students did not have difficulty with the technology. They did not think that the technology was confusing, and did think that it was easy to interact with. On the issues of specific technical aspects of the platforms, students were approximately neutral about seeing others screens, collecting and analyzing data, and finding patters in the data.

	Mean	Std. Error Mean
I thought the technology was confusing.	2.16	.055
I would have liked it to be easier to see other people's screens.	2.73	.056
I would have liked it to be easier to collect and analyze data.	3.07	.064
I thought finding the patterns in the data was easy.	2.89	.063
I thought the technology was easy to interact with.	4.10	.042

Table 4 – Student reactions to the Palm and badge technologies

Only two differences were found between student assessments of the palm experience versus the badge experiences. Students found the Palms slightly less confusing than the badges (mean = 2.03 vs. 2.35), and they found patterns in the data easier to find on the Palms (mean = 3.03 vs. 2.67). These differences are likely due to the interface on the Palm that provides much more information in a user-friendly way. No other significant differences were found between the Palm groups and the badge groups, showing that for the most part the experiences on the two platforms were quite similar across grades, gender and games.

In comparing the responses of males and females with respect to technology use, the only difference was that males thought that the technology was slightly easier to interact with than females (mean = 4.26 vs. 3.92), though this could be either because it was actually easier for them, or they are just more apt to praise their own technological skills.

Students were asked to name the specific features of both the Palms and badges that they liked the most and liked the least. While some of the features were generic across the games, others pertained to the specific game that the students were playing. For Live Long Prosper the "mating" aspect and interactions with other people were two of the most popular features for both the badges and the Palms. This is a very positive result that both platforms were able to capture the social interaction and investment in the game. Some component of data analysis was also popular across both platforms, though on the badges this was described as “finding patterns” without reference to the hardware whereas on the Palms they described it as viewing the data on the machine.

The least liked features showed similar results. Both “nothing” and finding patterns were some of the least liked features across the Palms and badges. On the Palms, however, students cited “dying” as the least liked feature. Again, we take this as a compliment to the technology, that they were so invested in the game that dying was a disappointment. On the badge platform, students didn’t like the centralized way that the badges needed to be reset (the badges couldn’t reset themselves like the Palms were able to when you died, due to their more limited interface).

When asked what features of the platforms they would change, most students expressed that they would not change anything. On the Palms they additionally cited one technical feature – data collection and viewing, as well as two game aspects (aging and mating). The data analysis capabilities that we built into the Palms are quite limited. Students can view each of their previous matings and the result offspring. This is a conscious decision to not provide too much automatic data collection, relying on the students instead to consider the appropriate data. On the badges they only cited technical features (lights, buttons and screens) among their top choices, showing that even for the students that did not see or use the Palms, that they felt somewhat limited by the sparse interface of the badges.

One class was able to play both the Palm and badge versions of the same game. This class started using Palms, and then played an extra class period using the badges. While there are clearly biases that might be present due to the order that the games were played, it is of note that students felt that the badges were easier than the Palms (14 vs. 6) but that the Palms were more fun (12 vs. 4). They were split in terms of which game they thought they learned more from. The fact that badges were easier contradicts the abovementioned finding on the Palms being easier to interact with. We suspect that this is because the badge experience came at the beginning of the game when the easy problems were still out there to solve

Discussion and Conclusions

The survey results clearly show that students using both the platforms found the learning to be engaging and motivating. Students were observed saying such things as "This is too much fun to be learning." Students exhibited the behaviors that we had hoped they would – interacting with each other, investigating the problem, collaboratively designing experiments and testing hypotheses. While we do not have specific subject matter assessments, students did feel like they learned a lot about technology, experimental design and the subject matter at hand. The simulations did allow students to explore several basic domain specific while developing their scientific inquiry skills. When students attempt to provide evidence for hypotheses, they often reveal misconceptions they have about the scientific method and the basic science involved. For teachers this type of activity might serve to identify what misconceptions their students still have about a subject even after instruction. In subsequent studies we will emphasize the objective quantification of these perceived learning gains.

We had originally conjectured that the Tag activities would be perceived as being more fun by the students, and that the brightly lit public display of information would increase the social collaboration within these groups. This, however, was not apparent in the data or in observations of the classes. Instead, there was very little difference in the way that the activities unfolded in the classroom, and the student reactions to their experiences. The small differences that were seen give a slight edge to the Palm in terms of usability and data collection. The students in this study had very little previous experience with Palms. It has been suggested that the Palms and Tags were nearly equally novel to these groups, and the results might be different with post-secondary students who have greater access to this technology. While we have yet to test this, trials with the first groups of post-secondary students don't support this. This might, however, be more important in other Participatory Simulations.

The results that females indicated that they were less interested in games than males was initially discouraging. Our games are explicitly designed with both competitive and collaborative aspects to appeal to both genders. The actual game play, however, showed little differences between genders. This suggests that we were indeed able to integrate elements that would appeal to both genders, and that it is likely that students have narrow notions of what "electronic games" are.

From these students' past experiences, the typical use of computers in the science classroom clearly doesn't reflect their actual uses and importance in science research and practice. This relatively cheap technology that we have introduced can be a way to not only motivate students but help them understand the relationship between science and technology. As teachers struggle to meet find ways to integrate technology into the classroom beyond internet research and word processing, this technology holds great promise for promoting collaborative learning.

The ability to disseminate Participatory Simulations, and the relative importance of the technology to the facilitator have been called into question. Since bringing this technology to the Palm platform, the technology has been distributed to dozens of teachers and the early results are promising. The next phase of this research will more closely examine how teachers incorporate this technology in their curriculum, and how it facilitates student learning and influences teacher practices.

The majority of the training that we now provide for teachers in using Participatory Simulations is in conjunction with a curriculum exploring Complex Systems, using StarLogo Software (Collela et al., 2001). Through the combination of these technologies we hope that students will build a deeper understanding of critical ideas in science, as well as the broader trans-disciplinary concepts of Complex Systems. Early evidence shows that this combination is highly effective, but future studies will examine these issues more closely.