Combining Collaborative Workspaces with Tablet Computing: Research in Learner Engagement and Conditions of Flow

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Abstract - **This paper reports on efforts to blend tablet computers with collaborative workspace technologies. An underlying conjecture is that this blend, evaluated with support from Microsoft Research and the National Science Foundation, may help increase learner engagement substantially. The pedagogical logic is that if an instructor can effect a high volume of precise feedback experiences, engagement levels and learning will climb. The intervention needs to afford the teacher a vivid lens on learner processing, and to furnish learners with means to construct representations naturally but electronically. It would also need to furnish means to mediate the rapid flow of those representations and instructor responses to them. These design principles were met with two collaboration workspace technologies and a TabletPC, critical because it allows users to make handwritten representations as one would do with paper and pencil. Results show significant increases in learner engagement that resulted from the TabletPCs/collaborative software combination, based on paper and pencil measurements, electronic engagement measurements, and interviews of faculty and students.**

Index Terms – collaboration, engagement, PDA, tablet computer, flow, group flow, social dynamics.

INTRODUCTION

This paper discusses an intervention in college engineering, physics and mathematics classes that relies on tablet computers, handwriting processing software (in this case, OneNote from Microsoft) and collaboration software that lets an instructor see what each student is doing at his or her computer (in this case, SynchronEyes from Smart Technologies). The data were taken from use of the approach in college calculus and differential equations courses. Our interest in this particular phase of research involves sustaining the engagement of learners in classroom activities.

Learner Engagement

The underlying conjecture of the work reported here is that this blend of technologies may help increase learner engagement substantially. The engagement of learners is the sine qua non or first principle of any form of teaching. It plays an especially important role in mathematics and fields of engineering and science, where the formation of conceptual models and competencies entails active manipulation of structures and their representations.

Complex factors determine how deeply engaged a student is in a classroom activity. These factors include motivation, perception of personal control in a task setting, and cognitive processing constructs such as self-regulation and strategy use [1]. They include more esoteric factors such as the subconscious mathematical processing leading to unexpected "Aha" experiences when one is ostensibly off-task [2, 3]. One of the most intriguing facets of research on engagement more broadly of great interest here involves a Vygotskian [4] proximal development zone concept of balance or goodness of fit between a person's performance competencies and the difficulty of a task in which the person is engaged. The application to educational environments entails the challenge of finding a good fit, achieved if a task's difficulty is at the outer reaches but not beyond a learner's ability level, and then learning occurs as both task levels and ability levels progressively expand.

This equilibrium or good fit is hard to individualize for each student; it is certainly difficult to establish for all students at the beginning of a class, and it is even more difficult to maintain throughout a full 50 or 80 minute class session. When it is lost, and the task either exceeds the student's skill level or is too easy, disengagement sets in. Flow theory characterizes the spectrum of disengagement as anxiety (task is too difficult) to boredom and apathy (task is too easy). A motivation for this study of tablet computing and collaborative workspaces is driven by the fact that assessment and feedback systems needed to maintain this equilibrium may involve dozens, hundreds or even thousands of discrete sampling and feedback events in a class period.

Flow

While engagement is a multivariate construct, its apex – full and unbroken immersion in demanding activities – may be characterized as the state of flow. Introduced as a psychological construct by Csikszentmihalyi [5], it has been widely researched – it is often characterized as intrinsic enjoyment or satisfaction while engaged in work or play, fully

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concentrated absorption in an activity whereby an individual loses a sense of time, or optimal or heroic performance in highly challenging or desperate circumstances. Because flow refers to such a broad range of intense human experience, it is not surprising that definitions and descriptions abound; a recent review reported sixteen different operational definitions [6], though usually only subtle variations separate these definitions. Csikszentmihalyi and collaborators continue to refine the concept [e.g., 7, 8], which, in popular terms, is sometimes referred to as performance "in the zone." Only a small fraction of the literature focuses on flow in formal educational environments. Shernoff, Csikszentmihalyi and Schneider [9] conceptualize flow in formal classroom settings as involving simultaneously high levels of concentration, interest, and enjoyment in a learning task, none of which are possible without maintaining an equilibrium of challenge and ability.

Enhancing learner engagement in the classroom, and doing so routinely, gives rise to a sublime question: Is the experience of flow while learning an inducible phenomenon? Twenty years after introducing the construct, Csikszentmihalyi [10] identified nine characteristics of flow situations which appear in Table 1. Among these nine characteristics are several that are states of consciousness (e.g., distorted sense of time, intrinsic reward in the activity or autotelic experience, disappearance of self-consciousness). The first five, though, can be at least *partly* designed or structured within learning environments and are factors that significantly affect learner engagement.

TABLE 1
Characteristics Of Play And Work Flow Situations
Csikszentmihalyi [10]

1.	There are clear goals every step of the way.
2.	There is immediate feedback to one's action.
3.	There is a balance between challenges and skills.
4.	Distractions are excluded from consciousness.
5.	There is no worry of failure.
6.	Action and awareness are merged.
7.	Self-consciousness disappears.
8.	The sense of time becomes distorted.
9.	The activity becomes autotelic.

The work reported here is, in part, a quest to design into learning environments the conditions (e.g., 1-5 above) that might lead to the emergent conditions (6-9) associated with flow and optimal use of one's faculties, creativity and complex performance skills. The logic path of this research is to look first at engagement as a point of entrée and then to try to match challenge and skill (point 3) in students' classroom experience.

The intervention is designed to help make this match of challenge and skill a good fit in part by opening up new "sightlines" for the teacher [12,20]. Additionally, it is designed to reduce cognitive downtime and to scaffold attention to taskings sufficiently to mitigate distraction (point 4). Further, it is designed to create the conditions necessary to allow the instructor the ability to provide feedback as we discuss below (point 2). Issues of "clear goals" and "no worry of failure" are important but beyond the scope of this paper. What is important to emphasize here is that the effort to increase learner engagement is part of a broader context, the entry point of which is increasing engagement by seeking equilibrium between skill and task, providing feedback, and minimizing distractions and downtime in coursework.

These factors are interrelated – for example, realizing the equilibrium between task difficulty and student ability levels is often tenuous and fragile in instructional settings. It is often hard for an instructor to find that balance for even a fraction of a class, and, when the balance is found, it typically fluctuates throughout a class session and is always at risk of being lost if the instructor cannot reliably assess whether students are "staying with" new material or conditions in the class session. Indeed, classrooms involve a great deal of guesswork by both students and teachers about each other. Feedback is a source of information that helps to keep task and skills relatively balanced and to help sustain learner engagement.

At the Air Force Academy we have attempted to understand and document what directed or purposeful attention to sustaining engagement might entail, beginning with the context that we could study and influence most closely: mathematics classrooms. At first approximation, this effort requires more intensive access by teachers to student work, and more intensive access by students to the teacher. Elsewhere, we have referred to this phenomenon as increasing the *interactional bandwidth* of the learning environment [11, 12], where bandwidth also refers to increasing interactional intensity between students, but that student-to-student interaction is not an element of the research reported here.

INTERVENTION

The design challenge of maintaining the delicate balance of learner competencies and task difficulty includes not only striking the right difficulty level at the outset of a classroom episode but also sustaining it throughout by scaffolding learner engagement via a system of rapid, fine-grained and natural teacher-student feedback cycles. Our working conjecture was that if an instructor could skillfully effect a high volume of unobtrusive and precise feedback experiences dedicated to maintaining learner engagement, engagement levels would climb. Thus the intervention would first need to provide the teacher with a vivid lens on learner processing, and then enable learners to construct mathematical representations naturally but electronically. Second, the intervention would need to furnish the means to mediate the rapid flow of both those representations and instructor responses to them.

These design principles were met with the hardware and software technologies mentioned above, namely Gateway TabletPCs (hardware), notebook software to prepare, store and retrieve handwritten material (OneNote from Microsoft) and collaboration software (SynchronEyes from Smart Technologies). The products work well, though this research is not product-specific but rather is organized around the functionalities they represent and the ways in which the functionalities enhance each other.

TABLE 2
CLASSROOM TIME USE SELF-REPORTING SURVEY

Engage-ment	Description
Level 1	What I am doing has nothing directly to do with the subject matter learning and it is unrelated to the teacher's lesson.
Level 2	What I am doing has nothing to do with subject matter learning but is related to the teacher's lesson, or is something I need to do for the lesson.
Level 3	What I am doing is related to the subject matter and to the specific material for the class, but I am not learning very much from it because the work is too trivial or easy, or else it is too hard.
Level 4	What I am doing is in the subject area and it is related to the lesson, and the level of difficulty is just about right for me, but I am really not interested and am not very engaged in it.
Level 5	What I am doing is in the subject matter and it is related to the lesson, and the level of difficulty is just about right for me, and I am working at it and am really engaged in it.
Other	(How would you define?)

Two of the necessary functionalities of the collaboration software are to furnish the instructor with either full-screen or thumbnail versions of the computer screen space of each student in the class (Figure 1) and to give the instructor means to provide comments back to the student station. It extends the functionality of "what you see is what I see" collaboration systems such as those developed by Hamilton [13, 14] and Greenberg, Hayne, et al. [15]. In modified form, it is the underlying platform for a current computer science curriculum research and development effort that integrates collaborative workspaces, digital libraries and multi-tier agent networks [16, 17]. The crucial functionality of the tablet hardware and software is to allow users to make handwritten representations and manipulations as one would do with paper and pencil.

Various tools contained in both technologies enhance their combined usefulness, but the primary instructional intent was to give the instructor **rapid and dynamically updated snapshots of each student's mathematics work**. With the TabletPC/SynchronEyes combination the instructor is able to make annotations on a student's work space and provide substantive, targeted feedback to a larger number of students in a shorter period of time by virtue of being able to see the work of all students from the teacher's computer monitor.

Four Design Intentions Related to Engagement

The question becomes, What difference does this intervention make? Our underlying design model suggested that if instructors could *see* student modeling activities more accurately and quickly, they could:

- answer questions or free up bottlenecks more quickly so that students could proceed;
- challenge students who may have completed a problem and need further direction;
- discreetly answer private queries of students resistant to raising their hand to publicly disclose ignorance on a subject; and
- provide directive monitoring and oversight to cadets who might otherwise "sit-out" a problem, an endemic issue among all students but especially among military academy students for whom exhaustion from training and athletic activities is a fixture of daily life.

These four distinct instructional intents of the intervention guided the design and refinement of the instructional setting. The "currency" of the intervention involved feedback cycles: a high volume of well-informed and timely responses by the instructor to automatically and unobtrusively updated representations of cadets' modeling processes.

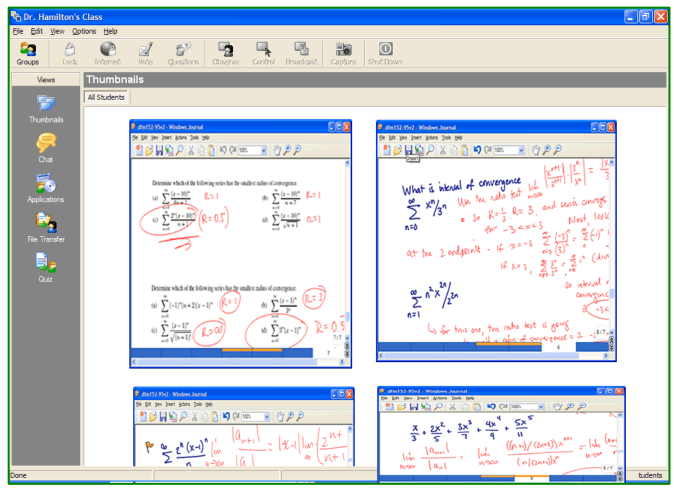

FIGURE 1
SCREENSHOT OF VIEW OF STUDENT STATIONS FROM TEACHER STATION

INSTRUMENTS AND MEASUREMENT

Measuring whether this arrangement produced an increase in learner engagement in mathematical activities is a challenge for instrument design. The technologies fundamentally altered classroom dynamics – for example, the TabletPCs evoked routine praise from cadets for their usability as writing systems. The students were issued the computers which were required first to meet the functionality of their existing notebook systems and then to provide the representational affordances of a tablet. One cadet noted "Everyone I show this to, they say Oh my gosh, I have to have one!" The TabletPCs passed the initial threshold of functionality and acceptability. Many of the features of the supporting software for digitizing the writing process (e.g., color coding, erasing, saving, exporting notes to web pages, etc.) further contributed to this acceptability. The collaboration software (SynchronEyes) changed the boundaries of personal privacy in the class – cadets were aware that anything that they wrote on their tablets could be electronically monitored.

TABLE 3
SELF-REPORTING OF LEARNER ENGAGEMENT (SEE TABLE 1) IN THIRD YEAR MODELING AND DIFFERENTIAL EQUATION COURSE.

	n	Level 1	Level 2	Level 3	Level 4	Level 5	Other
Freshman Class	308	10.3	8.4	26.8	21.6	27.6	5.4
Treatment Pre	15	6.9	7.7	34.0	20.9	29.1	1.3
Treatment Post	17	4.6	8.8	28.1	21.2	36.4	0.9
Change		-2.3	1.1	-5.9	0.2	7.3	-0.5
Control Pre	19	2.2	4.1	36.6	16.0	37.6	3.6
Control Post	20	5.8	6.5	28.8	22.0	28.5	8.5
Change		3.6	2.4	-7.8	6.0	-9.1	

While observing a student's work is a natural element of an instructor's task, remote monitoring is a new experience. This was not as problematic as the term "remote monitoring" might suggest, however, because all that could be monitored was the electronic workspace of the cadets – a workspace populated with the mathematical artifacts of the class session. What was more salient, perhaps, than a loss of privacy for this confined work area, was losing the opportunity for unobserved off-task behavior with the computer. It appeared in every interview, self-report and outside observation that students are less likely to engage in unrelated computer work when their desktops were always visible to an instructor.

Engagement Survey

Video data, written observer records, and the instructor's anecdotal observations support a conclusion that the cadets were consistently more engaged in their class activities than cadets in another section of the same course, a section that did not use the TabletPC/SynchronEyes combination. This paper reports the results of a "Classroom Time Use" self-report survey. The instrument (Table 2) was administered to this group and to another class of the same course, with the same instructor, and without the tablet/collaborative software combination. This comparison group used their standard issue notebook computers which matched the TabletPCs in virtually all features and power except for the capacity to accept stylus-based input, that is, without the capacity to create written mathematical representations and sketches in tablet form. Table 3 summarizes pre- and post- administrations in the two sections. Results from an initial administration to cadets in a core calculus section (roughly 30% of the freshman class) appear in the first row for comparison purposes.

The baseline experience cadets were asked to report on involved their current mathematics courses. Levels 1 and 2 reflect non-engagement in mathematical tasks; levels 3 and 4 also reflect non-engagement based on inappropriate difficulty level or lack of interest or motivation, and level 5 reflects perception of active and constructive engagement in classroom activity. Level 5 is, instructionally speaking, the payoff level.

Instructor Interviews

Part of the evaluation of the use of the combination of TabletPCs and collaborative software tools involves a series of clinical interviews of mathematics professors who are both new at (less than one month) and more experienced in the use of the combination.

RESULTS

Interview Results

Excerpts below from an Experienced Professor (EP) and Novice Professor (NP) provide another source of information that strongly supports the conjecture that combining TabletPCs and collaboration spaces (in this case, SynchronEyes) spurs higher student engagement levels. Relative to the ability to use a tool like Microsoft OneNote:

EP: "[This configuration gives] ...students multiple ways of keeping track of information. What I call multi-textured notes."

On the overall combination of the tablet/writing software/collaboration software:

EP: "[it's good to have the]… ability to rapidly assess what students are thinking and feeling... that's the difference. [Relative to using the system for testing, it is] …not just an enhanced version of a paper exam, but things that you could never do on a paper exam. It seems to me that [the tablet and software combination] provides lots of opportunity for that."

Both EP and NP commented on the affordance of collaboration software for reducing off-task behaviors during lecture and problem-solving sessions by virtue of the ability to observe students' desktops, and the novice user added after only a few sessions:

NP: "The other thing it does, when I put a student's work up on the projected screen or broadcast the work to the class, it instills a little bit of pride… what they've done…that helps them to stay interactive and focused on the lesson"

He further added that the collaboration software helps to keep students who might be struggling and reluctant to engage in seat work to stay on task, "again because I can monitor what they're doing with their tablets." In response to a question about whether the SynchronEyes collaboration software and the Tablet PCs detract from classroom activity:

NP: "the *combination* of the two, no. Without SynchronEyes, without me being able to see what everyone's doing, I think that can detract (without SynchronEyes; email and web surfing can be problematic)…the combination of the two… allows me to see if that's happening and stop it easier than I have before. I don't really see them as detracting, I see them as adding value and functionality… I definitely think it helps keep the students focused in the classroom whatever event that I'm doing, I think the attention level in the classroom regardless if I'm speaking or if they're working on some exercise the attention level is definitely higher than in my classrooms where I'm not using SynchronEyes."

Military academies combine a strenuous regimen of athletics for all students along with military training and academics. Class attendance is mandatory. For these reasons, it is likely that sleeping in class is a larger issue in a military academy than other colleges, which gives the following comment added weight:

NP: [In] my SynchronEyes class, since we've started using it, I don't think I've had one student fall asleep… Typically, in my other classrooms I have one or two students fall asleep, but not in the SynchronEyes classes."

Engagement Survey Results

The self-reports in Table 3 involve a third-year mathematical modeling and differential equations course. The average "high engagement" (level 5) rose over the course of the intervention. Students in the experimental condition using the tablet/tablet software/collaborative software blend reported increases in their class time engagement level. The time they reported in "level 5" engagement rose from 29.1% as a mean to 36.4%. The comparison group declined over the course of the experiment, from 37.6% to 28.5%. Because the sample sizes were relatively small (approximately 15-20 students in each of the four groups of pre/post x treatment/experimental), these results do not have sufficient power to make a claim of statistical significance. However, they are highly suggestive of the need to collect larger data sets to try and confirm that large positive gains in engagement are possible.

DISCUSSION

The interview data and the Engagement Survey data converge on a similar conclusion, that large improvements in engagement may be possible. The researchers' observations of a richer flow of classroom activity are supported by a strong increase in the self-report of engagement levels by cadets and by the interviews. These data tend to support the theoretical conjecture that a high volume of rapid feedback cycles can be technologically mediated with thoughtful and natural-feeling representational and communication systems, and that those feedback cycles may help to sustain the engagement of learners. The data do not speak directly to sustaining the delicate equilibrium of task challenge and learner competence, but rather to the high level of meaningful and interactive feedback that results in engagement. Certainly the immediate accessibility of the teacher and his or her ability to see student work and respond instantly across the classroom reduces the downtime of students who require assistance to reconnect to the task. As the interviews suggest, the affordance of desktop monitoring also makes it less likely that students are otherwise distracted in class, providing another positive factor in the root quest of creating and sustaining the conditions necessary for learner flow.

Limitations

It is important to mention several limitations in the self-reported data on engagement. The survey in Table 2 provides exemplars as aids for the self-reports, but learners undoubtedly vary significantly in their metacognitive sophistication and the accuracy with which they can estimate their time in the various levels. Also, the levels are specified at a rough granularity. A rigorous focus on engagement will require elaborations and nuances that cannot appear in a survey meant to give students a fairly unambiguous way to classify their personal attentional patterns in class activities. The survey data reported here involved paper and pencil instruments.

Limitations aside, the value of such a survey is that it furnishes a set of thought-revealing data points. The relatively small error term in the classification system of "other" is even smaller upon careful analysis of the explanatory text that accompanied those selections. In each case, the explanation readily fell into one of the first four levels of non-engagement. While in these instances the descriptions apparently were not sufficient for isolated students, cadets did not suggest changing the wording and generally concluded that the survey accounted for 100% of their time in class.

In Progress: Personal Digital Assistants (PDAs) with Experience Sampling Method (ESM)

To address some limitations of the paper and pencil approach, we recently developed a new tool for implementing the Experience Sampling Method [18, 19]. This innovation involves the use of PDAs programmed to pose questions similar to those in Table 2, with the PDA automaticaly requesting self-reports at four random times in each class. Preliminary sampling data comparing treatment and control classrooms agrees with earlier findings from the pencil and paper instrument: two control classes (without the SynchronEyes/TabletPC combination) reported being at "fully engaged" levels 40% and 48% of the time, while a comparable treatment class (with SynchronEyes/TabletPC) reported full engagement at a level of 68%. We will present more of this PDA-based data at the conference and will encourage FIE colleagues to use the Engagement Survey tool at their own institutions. The PDAs permit flexible alteration of the questions, the number of times the questions are posed, and the time periods over which they appear in the screen. With the PDAs we now ask students to identify the nature of the classroom activity at the time they are probed and also their sense of the relative difficulty of the material, which will permit analysis of engagement in relation to classroom activity and perceived difficulty of the subject matter.

NEXT STEPS

The use of the PDAs will provide important new data and comparisons – much larger data sets are easier to collect, and the data can be analyzed against other classroom and learning conditions. More significantly though, these efforts are part of the larger context discussed earlier: to determine whether providing professors greater sightlines into student cognition and activity may help keep students more fully immersed in course material. Beyond the task/ability equilibrium issue, it is clear that the rapid feedback that such sightlines furnish scaffold the students and, as a testable hypothesis, may reduce fear of failure. The sense that the screen is no longer a fully private space reduces some forms of classroom distraction, and certainly mitigates the distraction of disengagement.

TABLE 4
SIX PRINCIPLES OF FUTURE LEARNING ENVIRONMENTS [12, 20]

- **Increased sightlines in the classroom** – greater ability for everyone in a classroom, teachers and students alike, to see representations of conceptual models others are using in the classroom;
- **Increased emphasis on models and modeling** – a greater stress on systems of ideas and relationships both in how learning "tasks" are structured and in how assessment is carried out;
- **Increased connectedness** – individuals more meaningfully connected in the learning experience to each other and to those outside of the classroom;
- **Increased "one-to-one-ness" in the classroom** – a greater sense of individualization and customization for the individual learner under the management of a teacher, emulating a one-to-one tutoring experience.
- **Increased fluidity of learning context** – transfer to and from virtual systems, greater emphasis on heterogeneous competencies functioning together, greater integration of cognitive, social and affective dimensions, more interoperability of individual-social-machine knowledge forms.
- **Increased interactional bandwidth** – the capacity of the learning environment to mediate meaningful content and affective representations that are shared by all participants.

Whether this strand of research succeeds in finding conditions to routinely elicit learner flow, it appears a worthy pursuit because it holds so much promise in altering classroom dynamics. Continued research on flow should include deeper analysis of what that means in a learning context which, as noted earlier, is theoretically underspecified. The research also raises the tantalizing possibility of considering the notion of "group flow" – the conditions that elicit the phenomenon of optimal social performance in a whole-class learning situation.

Finally, the intervention reported here is one among many that might be analyzed according to a proposed set of principles to describe future learning environments. Elsewhere [12] the first author has discussed six principles to summarize learning environments of the future. Those appear in Table 4. The intervention discussed in this article, with the focus on increasing sightlines into cognition by combining collaborative spaces with tablet computing, emphasizes the first principle. However, it also touches on each of the remaining five in some form. The authors seek collaborators to refine real-time measures of learner engagement, and will freely share the PDA software with interested colleagues. The team also welcomes partners to help elaborate on the theme of principles to describe future learning environments, including those that present the promise of greater functioning "in the zone" or "in the flow" in college classroom settings.

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