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Breaking Away from the Laboratory: Using Lean-Computing Technology to Merge Theory-Based Learning and Experimentation

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Abstract

This ongoing research involves a departure from traditional laboratory instructional practices in that it seeks to forge a closer connection between lecture-based and laboratory courses. As such, the authors have devised a program that: (1) relinquishes a degree of control to students by providing them some flexibility in determining the subject of their experiments and in the development of experimental procedures and protocols, (2) uses mobile experimentation as a powerful and flexible tool in lecture-based coursework, and (3) expands the concept of the "laboratory" to include virtually everything outside of it. A pilot program in mobile experimentation and data acquisition that featured these approaches was conducted over two semesters. Students used PDAs to perform experiments using "real world" engineering systems that were found on or around campus. Such systems included: vehicle suspensions, elevators, auto-focus and strobe flash features of a camera, a suspension bridge model, mountain bike suspensions, and even themselves. Some groups measured and analyzed biomechanical data such as: impact forces on the leg muscles of a basketball player and the characterization of hand motion when performing repetitive tasks. The authors recognize that practical implementation of such activities on a large scale poses logistical and pedagogical challenges. However, preliminary assessment of the pilot program shows promise in overcoming these obstacles by exploiting the flexibility of PDAs. Further, the authors were excited to discover that the nature of the proposed experiments presented an opportunity to test three pedagogical hypotheses. (1) Since experimental test articles are not contrived, as in traditional labs, the student has to refine the experimental setup and repeat procedures several times. As the student makes common mistakes, he/she will better learn how to "debug" problems with the experimental setup, data acquisition, and overall procedures, thus achieving concept mastery in experimental design. (2) Results from the pilot program revealed that the nature of the activities resulted in a greater level of enthusiasm, engagement, and creativity among students, which will improve concept mastery. The authors have noted that this effect appears to be magnified with students whose grades tend to be average or below average. The authors posit that this approach is striking a chord in these students that originally inspired them to study engineering, and resonates with their particular style of learning. The authors wish to further investigate these connections through the use of PDA-based experimental activities. (3) Inserting experimentation into lecture-based courses places it temporally closer to learning theory. Thus, it enhances retention of key engineering concepts and theories. This was not feasible before the widespread accessibility of mobile computing technology.

Introduction

Enabling students to perform experiments shortly after learning theory and concepts in a lecture-based class is the focus of this educational research initiative. The authors hypothesize that if students have resources to perform a semi-open-ended experiment related to a concept(s) and/or theory(ies) that they have just learned in a lecture-based class, using a "real-world" system of their choosing, they will experience significantly improved retention of material (via active learning), a greater level of motivation, and a greater appreciation for the practical applications of the concept(s) and/or theory(ies). Specifically, students will demonstrate improved concept mastery and interest in using measurement methods to apply the concept(s) and theory(ies) they learn in class.

While this idea sounds logical, the challenges that must be overcome to implement it are numerous. The confluence of issues such as scheduling the use of laboratory facilities, large class sizes, and flexibility to accommodate changes in lesson planning can quickly render such an idea as unworkable from both logistical and pedagogical standpoints. However, recent technological advances in portable computing and experimental data acquisition have led the authors to recognize that these technologies have enormous potential to provide students with hands-on practical experience to complement the learning of scientific concepts and theories. This potential lies not only in overcoming the aforementioned challenges, but in opening up new opportunities for experimental activities that involve real engineering systems, versus the often-contrived laboratory exercises found in traditional engineering and science laboratory courses. Engineering systems that are present all over campus can be used in a myriad of ways to develop practical, low-cost, fun, and educationally valuable experiments for students at all stages of their engineering or science education.

Literature Review

The mobility and increasing functionality of PDAs has enabled innovative applications in many undergraduate educational settings. The authors conducted an extensive review of publications, conference proceedings, and NSF-funded grants and found that these applications fall into the following broad categories:

- Using PDAs to access and view course materials and to exchange ideas [1]. Some of these initiatives employed a "wiki" model [2].
- Using PDAs in a working-group environment to enhance real-time interactions among students, instructors, and student groups. These efforts typically involved PDA-based applications that facilitated class discussions or brainstorming sessions [3]. At MIT, researchers used PDAs as an integral part of "participatory simulations" of complex interactive systems that depended on human judgment and decision making [4].
- Using PDAs as intelligent tutoring devices, which adapted to a student's responses to questions and also used progress-based factors such as location, available time to study, and the time of day to adapt to a student's learning style and behavioral patterns [5].

- Using PDA-based software to guide a student through a procedure, such as plotting and interpreting pre-recorded or simulated experimental data [6, 7]. Such projects often featured Web-based content to enhance their flexibility and scope [8].
- Using PDAs in an observational setting, in which students used a PDA to: (a) manually enter experimental data and qualitative observations in the classroom or out in the field [9] (b) receive experimental data over a wireless Web connection [11], or (c) remotely control an experiment located in a campus laboratory [11, 12].

The projects in the first four categories differ from the proposed project in that a PDA is used in an individual and/or group environment: to display and retrieve content, or to prompt a student when performing investigative tasks. The last category more closely resembles the proposed project in that a PDA is used to monitor and/or control an experiment and to record experimental data.

While the proposed project indeed uses a PDA in some of these capacities, it goes beyond manual data entry and monitoring/control of an experiment by incorporating on-board high speed data acquisition hardware, local sensors, and signal conditioning circuitry. This creates a mobile, self-contained, and flexible experimental data collection and analysis tool that is applicable to a broader range of experimental activities.

Pedagogical Hypotheses

The pedagogical hypotheses to be tested as part of this study are:

- Inserting experimentation into lecture-based courses places it temporally closer to learning the theory and thus enhances retention of key engineering concepts and theories.
- The semi-open nature of the activities result in a greater level of enthusiasm, engagement, and creativity among students, which will result in a greater degree of concept mastery.
- Since experimental test articles are not contrived, the student will better learn how to "debug" problems with the experimental setup and procedures, thus achieving concept mastery in experimental design.

Objectives and Outcomes

The overarching objectives of this study are to:

- Establish a new, less-confining approach for educational content delivery in science and engineering experimentation using a combination of mobile off-the-shelf technologies
- Develop pedagogically sound strategies for effectively and practically integrating mobile measurement or PDA-enabled experiments into lecture-based courses
- Enhance students' experience with measurements concepts and methods
- The anticipated outcomes of this study are listed below:

- A Web deployed repository of PDA-enabled experiments that include experimental procedures, a list of equipment, and ready-configured virtual instruments that can be downloaded to the PDA
- Instruments to assess the impact and efficacy of the PDA-enabled experiments
- The deployment, use, and assessment of experiments to at least two institutions with undergraduate programs in Mechanical Engineering and/or Engineering Mechanics
- Students will demonstrate enhanced retention of theory
- Students will have increased enthusiasm for measurement methods and technologies

Pilot Project

The data acquisition hardware setup used in the pilot program was assembled entirely from off-the-shelf components. The main components are: a PDA (Dell Axim X51), a compact flash data acquisition card (National Instruments), and a connector board and cable for attaching sensors (National Instruments). All components fit neatly and securely in a soft-sided shoulder bag (PacSafe.) The setup is shown in Figure 1.

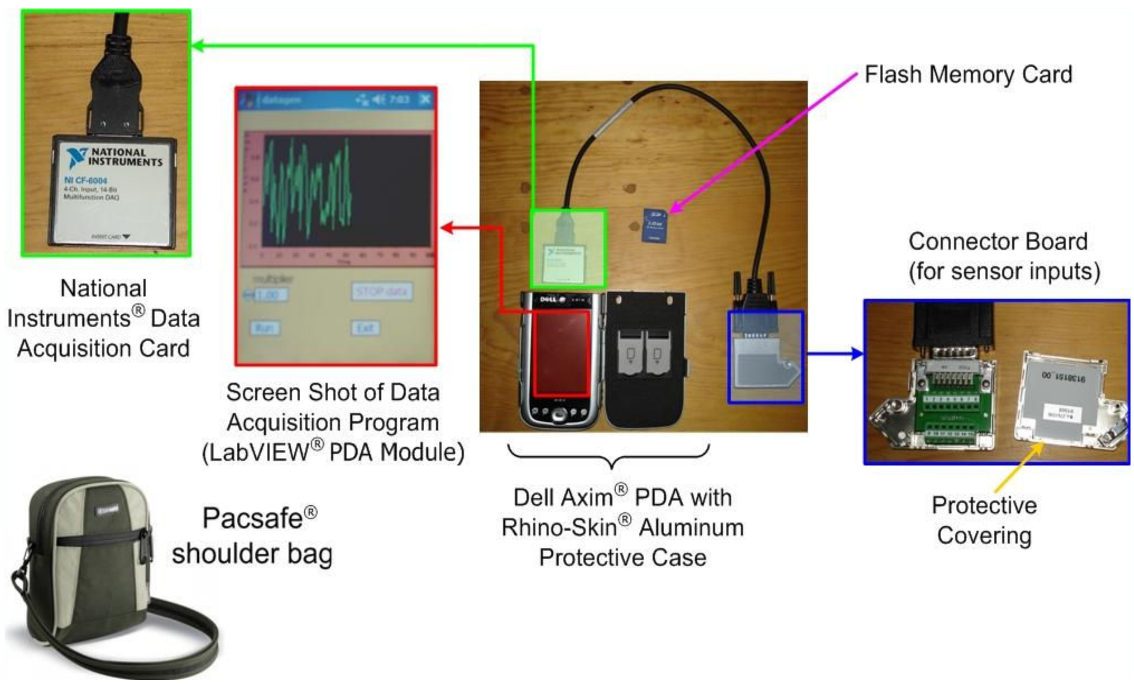

Figure 1: PDA-Based Data Acquisition Hardware

The authors implemented a pilot program to introduce the use of PDA-based data acquisition for experimental activities in his senior-level Dynamic Systems and Controls Laboratory course. For preliminary testing of the system and proof of concept, the authors chose an accelerometer (Endevco Istotron model # 256HX-100) whose power and amplification requirements could be

satisfied with three 9-volt batteries and a simple signal conditioning circuit that was built on a small breadboard. These materials were easily acquired and were small enough to neatly fit in the Pacsafe bag.
Thirty-two students among three laboratory sections were broken up into two-person groups. Each group was scheduled to perform the experiment in 90 minute blocks, many of which were scheduled during the regular laboratory meeting time. Some groups chose to meet at other times, which provided flexibility in scheduling and resource utilization, i.e., they could meet when other groups were not using one of the four available PDA setups. All groups completed their experiments over a period of two weeks. This demonstrates another important aspect of the flexible nature of the PDA-based system: a relatively small amount of PDA setups were able to service a multi-section class in performing various types of experiments. Since the nature of most of the experiments did not require laboratory classroom time to be scheduled, this provided even greater flexibility.

The students responded with a high level of enthusiasm and creativity. Lab reports for this activity spanned a wide range of topics, such as:

- Recording and characterizing the motion of an automatic sliding door
- Measuring the shock on several body parts of a basketball player making jump shots
- Measuring leg impact forces associated with running up and down a flight of stairs
- Comparing the responses of various vehicle suspensions to external inputs
- Analyzing the vibrations of a scale model of a suspension bridge when impacted at various locations on the structure
- Rcording and characterizing accelerations and forces felt by vehicle occupants during various road maneuvers and/or conditions

PDA-Enabled Suite Examples

This section details some of the particularly outstanding PDA-enabled mobile measurement experiments that were performed by students during the pilot program. These experiments were either: (1) completely devised by students or (2) they were suggested by the authors, but were significantly modified by the students in a manner that enhanced their novelty, creativity, and relevance.

Measuring and Characterizing the Vibrations of Vehicle Suspension Systems

In this activity, students used an accelerometer to measure the vibrations of the body of a car and other types of motorized vehicles. Student groups used their own vehicles, the author's vehicle, and also rode on public transportation to gather experimental data and perform analyses to characterize the dynamics of different types of vehicles. One group studied the response of a vehicle suspension system by pressing down on the bumper to provide a step input, or shaking the car with either periodic or random motion, as illustrated in Figure 2.

Figure 2: Vehicle suspension characterization - comparative studies

Analyzing Dynamic Biomechanical Data for Repetitive Hand Motion

One student team, that had a member who worked as a professional gamer, wished to investigate the forces and accelerations associated with repetitive hand motions. Each student took turns mounting an accelerometer on their hands and simulated repeated motion of shuffling and dealing cards, as shown in Figure 3. The students acquired several records of accelerometer data and performed a comparative study of the frequency, magnitude, and other patterns associated with repetitive hand motion. This activity and similar biometric measurement activities can serve as a experimental basis for understanding repetitive stress injuries that are commonly found among factory workers and computer professionals.

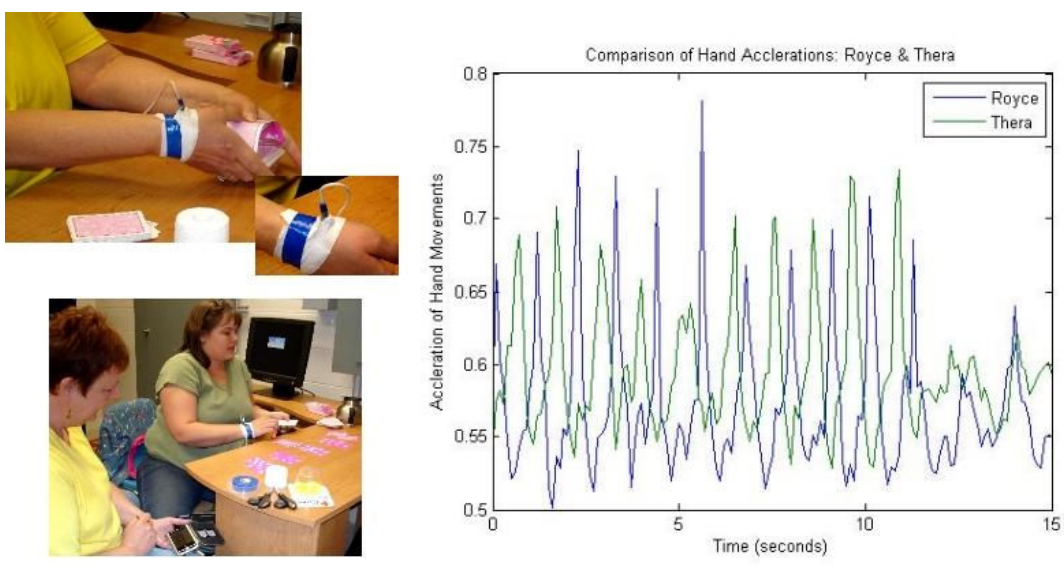

Figure 3: Study of Forces Involved in Repetitive Hand Movements

Comparing Shock and Vibration Levels Experienced by Mountain Bikers

One group of students examined the accelerations and energy absorption of a mountain bike subjected to shock environments, such as riding over a curb and a "road hump" at different speeds. The students mounted the accelerometer on the front fork of the suspension system to measure vertical accelerations, as shown in Figure 4.

A second group of students performed a comparative experimental study that involved two types of mountain bikes: one with front shock absorbers, and one without any shock absorbers. They performed "bounce tests" to better understand the suspension dynamics when subjected to an impact force. They also performed experiments in which they rode their bikes over different terrain profiles: a paved surface, an unpaved road, and rocky terrain, and recorded and analyzed acceleration time histories to assess how shock levels and energy absorption varied among bikes with different suspension systems.

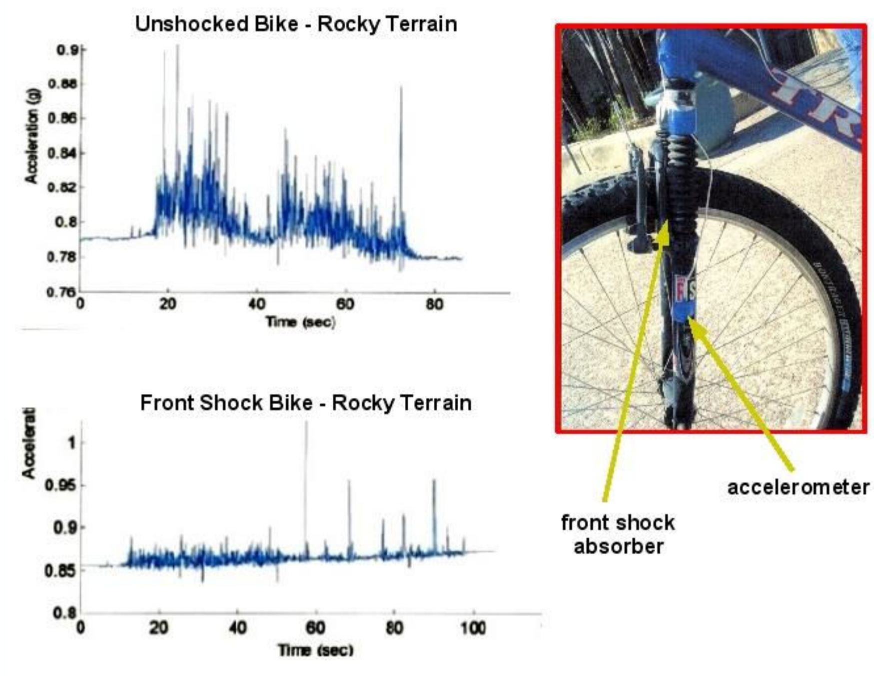

Figure 4: Mountain Bike Suspension Vibration Studies

Assessment Plan

Two levels of evaluation are planned – project assessment and student assessment. Project-wise, the authors will assess qualitatively and quantitatively the impact of meeting the goals and objectives previously outlined. Student-wise, the authors will assess students' mastery of measurements concepts and their ability to implement these concepts in hands-on applications.

Data collected will be aligned with the project's objectives and outcomes and gathered through various measures including pre- and post-achievement tests, surveys to assess learner perceptions, retention questions, and focus groups (for follow-up discussions of surveys). Pre-measures will be given to ascertain a baseline level of performance as well as initial or perceived level of interest in experimental activities in engineering classes.

The project will be evaluated in an ongoing as well as summative approach. With the ongoing or formative data, changes will be made to enhance instructional quality and student preferences/perceptions of the learning materials and approaches. The summative data will be gathered to see if the project's instructional objectives were met and to what extent learner improvement resulted. The evaluation strategy will enable us to develop and improve through an iterative process.

Project Assessment

The major purpose of the evaluation is to measure effectiveness of the proposed formats in achieving the objectives specified in the "Goal, Objective, Strategies, and Outcomes" section. The primary evaluation prototypes that will be employed are progress evaluation and summative evaluation as described in [13]. The four data collection methods that will be used are: surveys, focus groups, test scores, and observations.

Once a year, a focus group of students involved in the project will be formed. The focus group will be moderated by an external colleague evaluation expert and will identify those aspects of the project that can be improved upon for future optimization. Laboratory reports for the same PDA-enabled suite will be tracked and compared throughout the 3-year term of the project. Surveys will be administered periodically during the semester to evaluate student perception of aspects improved upon from previous iterations.

Student Assessment

Though related to the Project Assessment, we have chosen here to separate the student assessment. The Student assessment will focus more directly on measuring how well students master and apply Measurements concepts. This will be linked to design aspects of the curriculum model. The authors will define competencies – abilities that the students should be able to demonstrate to confirm mastery of related concepts. These competencies will be formulated in terms of constructs to facilitate quantitative measurement of concept mastery. Constructs are in the form of statements about student competencies that can be readily proved or disproved. An example construct statement would be: "The student should be able to characterize measured second-order response found in real-world applications." The key phrase of the construct being "the student should be able to...".

Constructs will be devised for each of the mobile measurement suites. Based on these constructs, questions will be designed to measure student mastery of core concepts. The questions will be formed into short quizzes. These quizzes will likely be web-administered so that results can be collected into a database to enable longitudinal tracking of impact of improvements and curriculum redesign that result from this project. As improvements are implemented over the course of this project, similar questions will be repeated with new sections of students to identify any trends that result from these curriculum improvements.

The assessment instruments will serve to (1) measure the qualitative and quantitative impact of the proposed methods on students' concept mastery and (2) quantify or measure the improvements resulting for redesigns of the mobile measurement suites. As a means of comparison, control groups will be created from students in courses or laboratories that cover the same or similar concepts using other methods than the associated mobile measurement suite. Qualitatively, the authors intend to determine whether the proposed methods encourage students' interest or enthusiasm in measurement concepts and technologies more effectively than other more commonly used approaches. This will be evaluated through surveys and focus groups. Quantitatively, the authors intend to determine whether the methods developed improve students' concept mastery as shown through improved test and/or assessment scores. Based on the mobile measure suite core competencies, the evaluator will design and administer assessment instruments to measure knowledge, comprehension, application, and analysis competencies.

Broader Impacts

K-12 Science Education Outreach

The scalable and customizable nature of mobile DAQ applications lends itself to science experimentation at the K-12 level. One of the authors put together a simple light sensing experiment along with several PDA applications of varying levels of granularity, which reflect the level of the student. The "Level 1" PDA program has two indicators that simply display whether the light sensor is exposed to "dark" or "light" conditions. The "Level 2" program takes this further, where the light levels are broken down into five categories: "very bright", "bright", "normal", "dim", and "dark". The "Level 3" program features two analog indicators, a slider and a meter, which displays the light level on a continuous scale, along with a digital display of the voltage level that is actually measured by the data acquisition card in the PDA. One of the authors "field tested" this experiment and the above-mentioned PDA applications with the assistance of his two nephews, ages 4 and 7, as shown in Figure 5.

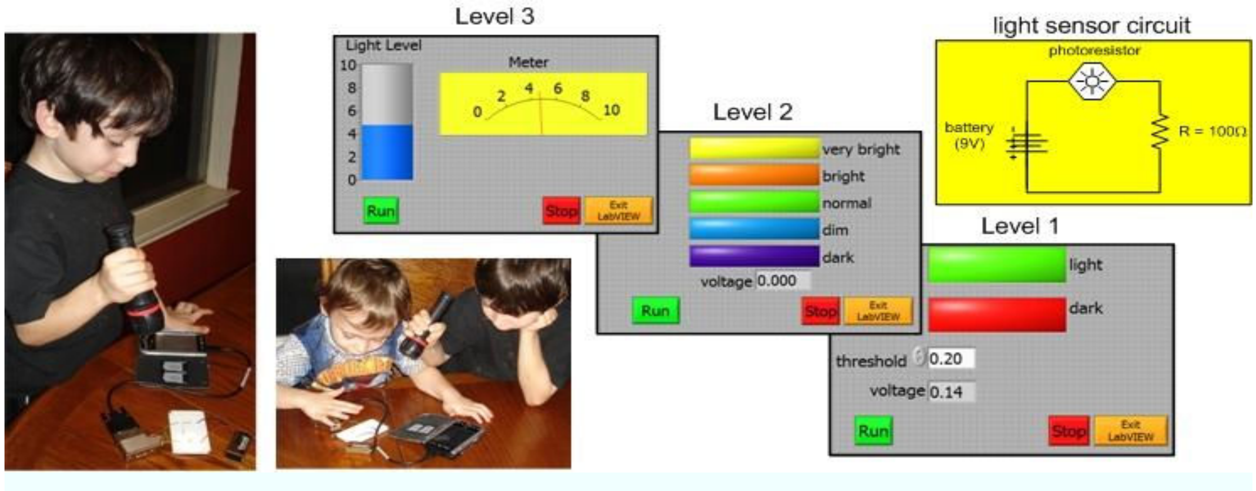

Figure 5: PDA-based light sensing experiment with elementary schoolchildren; actual PDA data acquisition program screen shots; light sensor circuitry

In this exercise, the student exposes the light sensor to varying light levels by carrying the PDA into different areas indoors and outdoors, by shining a flashlight onto the sensor from different distances, or by using his hand to cast a shadow on the sensor. As with the higher education activities described in this proposal, different types of sensors can be used to create simple, fun, and easily customizable science activities for students at all levels throughout K-12 education. These can include commonly used sensors such as those used to measure light intensity, temperature, force, velocity, etc.

A New Approach to Outfitting Laboratories

Through their experience with the pilot program, the authors have recognized that the PDA-based system developed for this project can be used for traditional laboratory exercises as well. The authors see its potential to supplant fixed-base lab equipment, since it provides a low-cost, flexible alternative to outfitting educational laboratories.

There are two possible benefits: (1) experimentation can become more accessible and ubiquitous within undergraduate curricula, since the lower cost of a PDA-based system would enable an institution to purchase a greater number of units, and (2) the lower cost would enable institutions that could not afford traditional, fixed-based laboratory equipment to purchase PDA-based systems that greatly expand the scope of their curricula.

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