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ABSTRACT

This study utilized the flow theory of intrinsic motivation to evaluate the subjective experience of 78 academically talented high school sophomores participating in an 8-day summer research apprenticeship program in materials and nuclear science. The program involved morning lectures on such topics as physics of electromagnetic radiation, energy transformations, superconductivity, and environmental analysis as well as laboratory experiments and tours of research laboratories. Findings included: (1) subjective experience could be classified into an enjoyment dimension and an involvement dimension; (2) the quality of subjective experience is optimal when a student's skills in the activity are high and the level of challenge is neither excessive nor insufficient; (3) Black male students were more likely than Caucasian and Asian males and females to perceive the research apprenticeship to be excessively challenging; (4) enjoyment levels were highest during unstructured apprentice activities such as lunch, recreation, and tours; (5) levels of involvement were highest during laboratory activities; (6) lecture activities minimized the potential for students to experience flow; and (7) laboratory activities minimized the potential for students to experience boredom. Appendices include the experience sampling form, a sample randomized alarm schedule, and a retrospective experience survey. (Contains 20 references.) (DB)

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QUALITY OF SUBJECTIVE EXPERIENCE IN A SUMMER SCIENCE PROGRAM FOR ACADEMICALLY TALENTED ADOLESCENTS

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ABSTRACT

In this exploratory and descriptive study, data are drawn from a sample of 78 academically talented high school sophomores participating in a research apprenticeship program at Argonne National Laboratory. The flow theory of intrinsic motivation is used to evaluate the quality of subjective experience during the various components of the apprenticeship. Findings include: 1) Subjective experience can be classified into an enjoyment dimension and an involvement dimension. 2) The quality of subjective experience is optimal when a student's skills in the activity are high and the level of challenge is neither excessive nor insufficient. 3) Black male students are more likely than Caucasian and Asian males and females to perceive the research apprenticeship to be excessively challenging; Black females are more likely than any other group to perceive insufficient challenges in the apprenticeship. 4) Enjoyment levels are highest during unstructured apprenticeship activities such as lunch, recreation, and tours; levels of involvement were highest during laboratory activities. 5) Lecture activities minimize the potential for students to experience flow; laboratory activities minimize the potential for students to experience boredom.

A fundamental goal of science education is to modify the learner's 'natural' notions about empirical phenomenon so that she may successfully participate in a community of people who share, use, and value a set of practices, tools, and communicative patterns for the construction of scientific knowledge (Hawkins & Pea, 1987; Roth & Roychoudhury, 1992; Smith, 1991). From the perspective of social constructivism, the development of scientific understanding occurs though a form of "cognitive apprenticeship" in which expert performance is modeled, and cooperative

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performances of the tasks are gradually shifted from expert to learner (Collins, Brown, & Newman, 1989). Speaking of his own scientific research experience before he moved into the field of education, the science education researcher Brandwein (1986) comments "There is nothing like working side by side with research scientists; one observes not only their ways of work, but their character-rooted habit" (p. 237). Numerous science programs based on an apprenticeship model have been implemented. Favorable effects on subject matter competency, science proficiency in laboratory methods and procedures, attitudes, self-concept, and student perceptions of science and scientists are indicated in several in-depth studies (Cody & Pizzini, 1976; Treagust & Cody, 1977).

The Research Apprenticeship in Materials and Nuclear Science

The Research Apprenticeship in Materials and Nuclear Science is an eight day program designed to encourage students to consider a career in science by providing hands-on laboratory experiences that demonstrate the principles and procedures of both materials and nuclear science. The program has been conducted since 1980 at Argonne National Laboratory for academically talented high school students from the Chicago area who have completed their sophomore year. The program targets sophomores in order to encourage them to take science and math courses beyond the minimum required for high school graduation. The 1992 program, which was the focus of the present study, was repeated in two sessions, the first beginning July 27 and ending August 5, and the second beginning August 5 and ending August 14. The hours of the program were 8:30 a.m. to 4:00 p.m. each day.

The program schedule included an hour of lecture each morning to present theories and information relating to the lab experiments which accounted for the bulk of the program. Lectures were presented by working scientists from Argonne National

Laboratory on the most current scientific ideas. The eight lecture topics presented during the apprenticeship were:

1. Physics of Electromagnetic Radiation
2. Energy Transformations
3. Nuclear Reactors
4. Education in the Former Soviet Union
5. Van De Graaf Accelerators
6. Environmental Analysis
7. Superconductivity
8. Magnetic Levitation

After the morning lecture, students broke off into groups of eight or nine to participate in one of five laboratory experiments:

1. Scanning Electron Microscope
2. X-Ray Crystallography
3. Gamma Ray Spectroscopy / X-Ray Fluorescence
4. Gas Chromatography / Mass Spectrometry
5. Absorption Spectroscopy--Infra-red & Ultra Violet

Each laboratory experiment lasted one day, two and one-half hours in the morning and three hours after lunch. Formal write-ups were required of the students for each laboratory experiment.

The apprenticeship program also included a safety orientation, tours of selected research Laboratories at Argonne (Advanced Photon Source, Tandem Linear Accelerator System, Intense Pulsed Neutron Source), a tour of the University of Chicago, a film on the history of Argonne, a special lecture on "Chemical Imbalances and Violent Behavior" by Dr. William Walsh of the Health Research Institute, and social and recreation activities.

The following sections provide detailed descriptions of the five laboratory experiments.

Scanning Electron Microscope

The Scanning Electron Microscope Lab is a hands-on laboratory experience that teaches kids how to operate an advanced scientific tool. The lab's learning objectives are for students to: (1) understand the practical applications of the scanning electron microscope (SEM), (2) understand how the scanning electron microscope functions, (3) realize the relationship between the wavelength of the electron source and the resolution of the image, (4) be able to prepare a sample for imaging, and (5) be able to operate the SEM.

Typical designs for light microscopes utilize a beam of light rays (photons) focused on a specimen with the use of a glass condenser lens. Light is then transmitted through or reflected off the specimen in order to observe its surface structure. However, the wave nature of light, which is the source of illumination for the light microscope, limits the degree to which the specimen can be magnified and, more importantly, the ability of the light microscope to make the individual parts of an image distinguishable (resolution).

The resolution of a microscope is strongly dependent on its source of illumination. In the scanning electron microscope, the source of illumination is an accelerated beam of electrons. The beam of electrons interacts with the specimen to produce low energy electrons at the specimen's surface. Because electron beams have an associated wavelength that is much shorter than light, much higher resolution can be achieved with the SEM. The SEM is thus an important tool in materials science research because it enables scientists to see the micro-structural arrangement of a given material and understand it's related macro-properties.

A variety of samples were available for students to use in the lab, including a superconductor, a computer microchip, and various insects. Students could, if they chose, bring in their own sample or collect their own bug. Before the sample could be used, it had to be prepared by coating it with an extremely thin layer of material that conducts electrons. In this lab, gold was used as the conductive coating. Although there was only one electron microscope available per group of eight students, each student had multiple opportunities to operate the instrument. The scanning electron microscope is basically composed of four major systems, the electron beam system, the data collection system, the display system, and the vacuum system. All of these systems are controlled by the operator of the microscope in order to achieve the optimal conditions for a particular specimen. Students used a special Polaroid camera to take photographs of the highly magnified images they produced with the SEM. Students were permitted to keep all photographs they had taken.

The sequence of events for the SEM lab begins with a 40 minute overview of the SEM. In the overview, students are asked to identify a computer microchip that is passed around the room. After everyone has had a chance to handle and observe the computer chip, it is placed in the SEM to demonstrate the operation of the machine and its magnification capabilities. Each student then takes a turn operating the SEM, loading the camera, and taking a picture. In the afternoon students are able to select their own sample to prepare for the SEM. The preparation process, called sputtering, involves plating the sample with an extremely thin coating of gold. After completing the sputtering process, students again take turns observing their sample through the SEM and taking pictures.

The lab was taught by a local high school physics instructor who was working at Argonne as a Teacher Research Associate in a program providing secondary school science teachers the opportunity to participate in ongoing research projects in Department of Energy laboratories.

X-Ray Crystallography

X-ray crystallography is a process by which scientists use x-rays to indirectly examine the arrangements of atoms and crystals in a given material. The lab aims to familiarize students with both the procedures of x-ray crystallography and its theoretical framework.

The lab begins with the instructor, a high school physics teacher, giving a brief introductory lecture on the physical properties of crystals and the arrangement of atoms. After the 30 minute lecture, students learn how to operate a special camera, called a Debye-Scherrer camera. The camera records the unique patterns of x-rays that are generated when x-rays interact with the atoms in a compound. Each student cuts and prepares the film and loads it into the camera. The instructor positions the camera on an analytical x-ray machine that generates x-rays that collimate on the sample. In this lab, copper wire is used as the sample to be identified. After exposing the film, students apply developer and fixer to process the film. Students are then instructed how to read the x-ray pattern and turn it into useful data.

Depending on the composition of the material, x-rays will scatter differently from the sample leaving characteristic marks on the film. Students measure the distance between the lines that show up on the film using a reader. The measurements are used in a long mathematical procedure to calculate the relational positions of atoms in the sample. Students can then use a chart to identify the compositional elements on the basis of the distance between atoms in the sample.

X-ray crystallography is often used by research scientists to identify the composition of an unknown material. It is widely used in superconductor research.

Gamma Ray Spectroscopy / X-ray Fluorescence

Gamma ray spectroscopy (GRS) is a procedure for identifying radioactive materials by measuring the characteristic gamma rays produced by radioactive isotopes. Gamma rays are typically produced from nuclear decay in radioactive isotopes. The GRS lab seeks to involve students in actively measuring gamma rays and using their characteristic energies to identify unknown isotopes. The GRS lab emphasizes not only the process by which scientists identify radioactive sources, but also the contemporary applications of the technique in the fields of nuclear medicine (using radioactive tracers to visualize bodily systems, treating cancer with radiation therapy), environmental science (analyzing the hazardous waste from nuclear reactors), and astronomy (locating the sources of cosmic rays in space).

X-ray fluorescence (XRF) is an analytical technique for determining elemental composition involving the measurement of characteristic x-rays produced from excited atoms. Radioactive sources that naturally give off x-rays (typically Iron-55 or Cadmium-109) are used to excite the atoms in a non-radioactive sample. In XRF, the elemental composition of the sample is determined by using a process of x-ray detection and identification similar to that in gamma ray spectroscopy. Unlike GRS, however, XRF is used to identify non-radioactive materials. XRF is widely used in environmental science to determine pollution levels in air and water samples, in forensic science to authenticate materials and identify samples of hair, soil, drugs and other crime-related substances, and in materials science to determine the composition of elements in synthetic materials.

The purposes of the lab are: (1) to enable student to make measurements of phenomenon that cannot be seen by the human eye, and (2) to demonstrate how scientists can safely use radiation as a research tool.

The lab starts off in the morning with an explanation of the electronics involved in the process of measuring the gamma ray energies emitted from radioactive isotopes. Students use a known radioactive isotope (Cobalt-60) to calibrate the detection system in terms of gamma ray energies. The detection system is calibrated by placing the Cobalt-60 on the gamma ray detector. The gamma ray detector is usually a semiconductor made of Germanium and cooled with liquid nitrogen. The detector, a foot-long metallic cylinder, functions like an eye that sorts information by gamma ray energies much as the human eye distinguishes light as colors. This information is transmitted to computers which sort the data and generate graphical representations corresponding to the energies of gamma rays. After the students have calibrated the detection system, unknown isotopes are placed on the detector for identification. Information is again sent to computers for graphical representation. This time students identify the radioactive isotopes from the encrypted gamma ray energies with the use of a standard gamma ray identification chart.

The afternoon session is devoted to x-ray fluorescence. The x-ray detection system is first calibrated by analyzing a sample with known elements. The technique of XRF is then used to identify elements from an unknown sample. For this technique, students provide their own samples (jewelry, a paint chip, soil, etc.) which are placed near a radioactive source for excitation. The lab is contextualized by posing the problem, "Suppose you have a ring and you want to find out what it is made of, whether it is gold or silver or some other element? How could you go about it?" One of the students donates a ring or some similar item and the technique of x-ray fluorescence is used to identify the characteristic spectral patterns of x-rays emitted by the compositional elements in the material. The detection of characteristic x-rays from the sample is made using a semiconductor detector made of silicon doped with lithium and cooled with liquid nitrogen. Standard x-ray identification charts are then compared to computer generated graphical representation of the x-rays emitted from the sample to identify its elemental composition

Before joining Argonne's Division of Educational Programs, the instructor of the lab worked in the reactor control group at Argonne National Laboratory as an electronics technician. His specialty is radiation detection.

Gas Chromatography / Mass Spectrometry

The Gas Chromatography/Mass Spectrometry (GC/MS) laboratory is a hands-on experience that introduces students to state-of-the-art analytical instrumentation, and some fundamental notions of organic chemistry. The objective is to expose students to the operation and capabilities of the mass spectrometer and the physical and chemical ideas underlying its use. The laboratory consists of an introductory lecture, high and low tech hands-on experiments, and problem solving sessions.

The 45 minute morning lecture explains why gas chromatography/mass spectroscopy is such a powerful analytical tool, how the instrumentation works, what is happening during the procedure at the molecular level, and how the procedure is relevant to the students' lives (e.g., pre-employment drug testing). The lecture also serves to introduce the analysis of mass spectra. The concept of deducing a compound from the fragments it breaks into is first illustrated with a word analogy (the students are given "word fragments" which they quickly determine spell out a word such as *molecule*). Examples of simple spectra are then worked out and finally sophisticated concepts such as the use of neutral isotopic abundances to determine the elemental composition of an unknown are demonstrated by example.

Two low tech experiments are demonstrated before breaking for lunch. The first involves thin layer chromatography of food colors, which is a beautiful illustration of the power of chromatography, and the second involves a mock-magnetic mass selector that demonstrates how to sort out different mass particles.

In the afternoon session, students begin by "autotuning" the computer controlled mass spectrometer. During this calibration process they are asked to calculate which fragments of the tuning compound are responsible for three different mass peaks used to set the instrument's mass scale and to predict the relative abundances of the isotope peaks using a table of natural abundances. This amounts to a simple exercise in arithmetic, but serves to introduce the notion of how breaking different bonds in a molecule creates different mass fragments.

Next, an air sample is analyzed. The students are asked what compounds are expected to be found in the air sample, and to predict what mass-fragments will result from each gas. The constituents of air are relatively small molecules and thus do not present many choices for fragmenting. However this activity familiarizes the students with the system's software. A simple example is then run and the spectral analysis is treated as a group activity

Finally, a mixture of "unknowns" is run. While the mixture is running, each student chooses a 3-D molecular model of one component and, working backwards, predicts a theoretical mass spectrum for the molecule (i.e., major fragments and relative abundances of parent peaks and their isotope peaks). The real mass spectra are then analyzed and the students decide whose compound is responsible for each spectrum and why.

All stages of the lab are augmented with thought experiments, such as *How would GC/MS be helpful in detecting a leak in a vacuum chamber? Why is there so much helium in the air sample? How could GC/MS help identify a pollution source?* and so on.

The primary laboratory instructor holds an M.S. degree in physical chemistry from the University of Chicago and has extensive research experience with high resolution spectroscopy. The other instructor holds a degree in chemistry.

Absorption Spectroscopy--Infra-red & Ultra Violet

The Absorption Spectroscopy lab is designed to introduce the practical applications for a range of advanced instrumentation and the theory underlying their use. Absorption spectroscopy is an important technique of instrumental analysis that involves measuring the amount of radiant energy absorbed by a substance. The technique is widely used to identify the elemental composition of organic compounds by revealing how the carbon atoms are bonded and arranged. Although absorption spectroscopy does not provide as much information as gas chromatography/mass spectroscopy, it is more useful for quality control and batch processing because it is a relatively quicker procedure.

Absorbence spectroscopy techniques can be applied to the visible spectrum, as well as to the ultraviolet and infrared portions of the electromagnetic spectrum. The lab explores spectral composition of various compounds within the visible spectrum during the morning session and both infrared and ultraviolet spectrometry during the afternoon session. The first half-hour of each session is devoted to a discussion of the operation and application of the relevant instrumentation. Students then spend the remainder of the lab participating in several analyses.

To analyze the visible spectrum, the lab used an instrument called the Spectronic 20 which takes white light and separates it into its component colors in order to determine the portion of the electromagnetic spectrum that will be absorbed by the elements in a sample. Students begin by taking a piece of white chalk which reflects the entire visible spectrum and using the Spectronic 20 to identify the various colors of the visible spectrum and their associated wavelengths. The Spectronic 20D (a digital version of the instrument) is then used to analyze the food dyes on M & M candies. Every food dye absorbs a certain wavelength of light depending on its color. Next, the ultraviolet instrument was used to analyze sun block lotions. A certain wavelength of light in the ultraviolet region causes sunburn (erythema). Students determined which sun block was most effective in absorbing this harmful radiant energy. Cost comparisons between different brands were conducted to see which gave the most protection for the least amount of money. The final two activities used fourier transformation of the infrared spectrum to determine the thickness of a thin polymer film and to determine an unknown concentration of a liquid organic mixture using the Beer's Lambert Law, which relates concentrations of the organic sample through the amount of light absorbed.

The Absorption Spectroscopy lab is guided by an instructor with a degree in chemistry emphasizing instrumental analysis and organic chemistry.

Objectives of the Program

The overall purpose of the summer program, is "to stimulate the students' interest in engineering and/or the sciences, to familiarize students with the kind of work done by engineers and scientists, and to make students aware of the academic requirements for acceptance into engineering or science programs" (Argonne National Laboratory, Division of Educational Programs, 1980).

A Strategy for Evaluation of the Program

In order to determine the extent to which the objectives of the Argonne Research Apprenticeship are being met, it is suggested that descriptive studies of the subjective experiences of student participants be conducted. The flow (i.e., optimal experience) theory of intrinsic motivation offers a penetrating strategy for evaluating the program's impact. Successful socialization to work is most often evaluated in terms of knowledge and skill acquisition or the development of cognitive personality traits such as perseverance or problem-solving. Yet, the "capacity to find enjoyment and satisfaction in agentic activity" is perhaps the most important context for assessing socialization for adulthood (Csikszentmihalyi, 1990; Larson & Richards, 1989).

Csikszentmihalyi's (1975, 1978, 1982a, 1988, 1990) theory of flow in consciousness considers the colorations of subjective experience to be the primary determinants of occupational and recreational pursuits. The flow theory proposes that a person acts according to genetic drives (such as hunger or sexual desire), cultural drives (seeking and maintaining social and economic success), and intrapsychic drives (establishing growth in the order and complexity of consciousness). However, behaviors driven by intrapsychic factors are presumed to be superior because (1) they mediate and prioritize between genetic drives and cultural drives, thus reducing motivation to its lowest order of organization, (2) they are autotelic in that they have a purpose that is intrinsically satisfied by the behavior itself, and (3) they provide the optimal conditions for high quality subjective experience.

Specifically, it is presumed that intrapsychic drives direct the ways in which a person elects to invest their attention. Personal growth and learning require the investment of psychic energy in concentrated involvement and interaction with complex information. The optimal experiential state in which one is deeply involved and psychic energy is highly focused has been given the technical term "flow". Two universal preconditions are required for flow:

1. A person should perceive that the environment contains high enough opportunities for action (high challenge).

2. A person should perceive that their own capabilities to act are adequate (high skills).

A great deal of research has investigated the underlying concepts in flow theory. The ratios of subjectively experienced challenges and skills that are associated with ongoing fluctuation between positive and negative states of experience have been empirically identified in several studies (LeFevre, 1988; Massimini & Carli, 1988; Massimini, Csikszentmihalyi, & Carli, 1987). As predicted by the theory, optimal experience is most likely to be reported when challenges and skills are perceived to be both high and in balance. States of apathy are associated with lower perceived challenges and skills. Boredom and anxiety are associated with challenge/skill ratios that are imbalanced in the expected directions.

DATA AND METHODS

Description of the Sample

The population of interest in this study is academically talented high school students who completed their Sophomore year in June 1992. The sample of students was drawn from over 200 high schools located in the greater Chicago, Illinois area. Chicago area schools were asked to encourage students in the top 10% of their sophomore class to apply for the Argonne research apprenticeship. Seventy-eight students from 51 high schools were selected from a pool of 122 applicants. Twenty-five students were from the city of Chicago and fifty-three from the surrounding suburban area. Criteria for selection included grade point average, science and math background, a short essay on the appeal of a certain scientific discipline, and recommendations from school science teachers. Science teacher recommendations provided information about the student's academic ability, initiative, curiosity about science, oral communication skills, writing skills, and problem solving skills. In order to compensate for groups that are traditionally under-represented in the sciences, the selection process accorded greater preference to qualified female and minority candidates. The breakdown of participating students by gender and racial background can be found in Table 1 along with their self-reported mean grade point average (A=4.0) and class rank percentiles.

All students had completed two years of high school mathematics (algebra and geometry) and at least one lab science course (biology or chemistry). All but seven students had taken mathematics and science in advanced placement honors courses Most students also had received academic awards and prizes in science fairs and scholastic competitions.

Table 1

Student Characteristics: Mean GPA (A-4.0) and Class Rank Percentiles by Gender and Racial Background

	Asian	Black	Caucasian	Hispanic	Total/Mean
Males	13	5	20	0	38
GPA	4.16	3.62	4.10	--	4.06
Rank %	9.60	13.75	2.68	--	6.50
Females	16	5	16	3	40
GPA	4.04	3.74	4.11	3.69	4.00
Rank %	1.85	7.26	4.63	6.32	3.97
Total	29	9	36	3	78
GPA	4.09	3.68	4.10	3.69	4.03
Rank %	5.32	10.50	3.55	6.32	3.54

Assessment

The study used the Experience Sampling Method (ESM) (Csikszentmihalyi & Larson, 1984; Csikszentmihalyi, Larson, & Prescott 1977) with a subsample of 16 students, 8 from each session, to measure the quality of student experience during the apprenticeship program. Quality of experience was further measured with the entire sample of 78 students using a retrospective experience survey.

Experience Sampling Method

In the Experience Sampling Method, each participating student was required to wear a programmable wristwatch and carry a booklet of self-report forms during their research apprenticeship. Using the multiple-alarm feature of the wristwatches, students were signalled at random times throughout the period of their research apprenticeship.

In response to the signal, each student completed a brief self-report form, the Experience Sampling Form (ESF, Appendix A). The ESF takes less than two minutes to complete and consists of 17 items indicating the respondent's thoughts, activities, and location, and measuring the quality of subjective experience and perceived skills and challenges.

The wristwatches were pre-programmed to sound an alarm approximately seven times each day for the eight days of the research apprenticeship, providing a total of 56 randomized self-reports for each student. Five signals each day occurred during research apprenticeship activities -- one during the daily lecture, two during the morning activity session, and two during the afternoon activity session. The remaining 16 self-report signals occurred at random points during the hours when students are not actively participating in structured research apprenticeship activities -- either at home or during the hour-long lunch break. Alarm-signals were not permitted to occur within 15 minutes of one another. Each student had an individual randomized alarm schedule which changed each day. A sample alarm schedule is provided in Appendix B.

Retrospective Experience Survey

Information, parallel to that obtained with the Experience Sampling Method, was alternately obtained from a two-part retrospective experience survey to be filled out at the beginning and end of the research apprenticeship (RES, Appendix C). The RES entry form asked students to reflect back upon their high school science education and respond to questions about their experience. The exit form is identical to the entry form except that it addresses student experience during the research apprenticeship. The retrospective experience data was used for making gender and ethnicity comparisons and for validation of ESM data.

Analysis of the Data

The purpose of this study is to investigate the quality of subjective experience during a summer science program for high school sophomores as it relates to perceptions of skills and challenges. Although flow theory generally postulates four dimensions of subjective experience (emotion, activation, cognitive efficiency, and intrinsic motivation), a factor analysis was conducted to ascertain the construct validity of the internal structure of subjective experience in the present sample. The reliability and validity of the two alternative measures of subjective experience and the representativeness of the ESM group were also examined. The flow model was tested by examining the relationship between subjective experience and perceived skills and challenges.

An evaluation of the apprenticeship program was then conducted by identifying variations in subjective experience as a function of race and gender and describing the patterns of student experience and perceived skills and challenges in terms of program components.

Results

Validity and Reliability of Experience Measures

In order to compensate for individual differences in self-report tendencies, each item on the experience sampling form was positivized and normalized at the individual level. Consequently, a value greater than zero for any particular item indicates an experience that is rated higher than that student's weekly average. A negative value registers a below average experience. The variable *How challenging is the activity for you? (too challenging / just right / not challenging enough)* was exempted from the normalization process because the likert scale for this item is inherently standardized to the individual.

In order to test the construct validity of Csikszentmihalyi's classification of subjective experience variables with the present sample, a factor analysis was conducted with the 14 items on the Experience Sampling Form measuring quality of experience. Table 2 lists the factor loadings (principal component analysis with varimax rotation) for each item. The 14 items are reduced to two factors which account for 54% of the variance. The first factor, accounting for 43% of the variance, contains items reflecting the more immediate aspects of experience and will be designated *enjoyment*. The second factor, accounting for 11% of the variance, is composed of items representing a purposive interpretation of experience and will be termed *involvement*. On the basis of the factor analysis an *enjoyment* variable and an *involvement* variable were computed by taking the mean of their component variables. The creation of two subjective experience variables will help focus the research objectives by simplifying the data analysis

Additional support for the validity and reliability of a two factor subjective experience construct is provided in the multitrait-multimethod matrix shown in Table 3. The monotrait-monomethod reliability coefficients reveal a high internal consistency for both the enjoyment (.89 RES, .88 ESM) and involvement (.82 RES, .83 ESM) scales. Of greater interest than the anticipated high reliability estimates is the evidence for convergent validity indicated by high and significant correlations between measurement of each trait by the two different data collection methods (.66 enjoyment, .59 involvement). High convergent validity indicates that the enjoyment and involvement factors can sustain inference under both measurement conditions. Unfortunately, the evidence for discriminant validity is less solid. Although the monotrait-multimethod coefficients are higher than the multitrait-multimethod coefficients, correlations between the two traits using the same or different methods are quite high. A strong relationship between different aspects of subjective experience is, however, consistent with flow theory. Nevertheless, an important difference between the ESM data and the RES data

TABLE 2

VARIMAX-ROTATED FACTOR LOADINGS FOR FOURTEEN ITEMS ON THE EXPERIENCE SAMPLING FORM

Item	Factor Loadings	
Enjoyment:		
Joyful / Distressed	.82	.10
Excited / Afraid	.82	.18
Pleased / Angry	.81	.20
Appreciative / Resentful	.67	.17
Creative / Dull	.56	.47
Energetic / Tired	.52	.38
Active / Passive	.51	.50
Involvement:		
Involved / Detached	.24	.80
How well are you concentrating?	.09	.78
Is the activity interesting?	.34	.72
Do you wish you were doing something else?	.35	.60
Is the activity important to you?	.16	.58
How hard is it to concentrate?	.05	.55
Clear /Confused	.39	.52

must not be overlooked. The quality of experience was rated higher by students in retrospect than during the program (enjoyment: m=1.46 vs. 0.73, $t_{(15)}$=-3.10, p<.01; involvement: m=1.94 vs. 1.27, $t_{(15)}$=-4.56, p<.001). These differences may be attributed to the vagaries of memory or to the lack of specificity in the retrospective questionnaire. In any event, because the ESM records immediate experience before a reevaluation and reinterpretation can take place, it will be considered the more accurate of the two measures. In fact, during the pilot study, when students employing the ESM were asked which of the two data collection methods provided the more accurate description of their apprenticeship experience, 11 of the 12 students felt that the ESM was the more accurate.

TABLE 3

MULTITRAIT-MULTIMETHOD MATRIX OF SUBJECTIVE EXPERIENCE VARIABLES

	Random Experience Survey		Experience Sampling Method	
Variable:	Enjoyment	Involvement	Enjoyment	Involvement
RES:				
Enjoyment	(.89)			
Involvement	.68**	(.82)		
ESM:				
Enjoyment	.66*	.52	(.88)	
Involvement	.42	.59*	.63**	(.83)

* p < .01
**p < .001

Note 1: Monomethod ESM correlations based on 797 individually normalized self-reports.
Note 2: Monomethod RES correlations based on 78 student reports.
Note 3: Multimethod correlations based on RES reports and mean non-normalized ESM ratings in 16 students.
Note 4: Values in parentheses are standardized item alpha coefficients.

Having demonstrated the validity of a two factor subjective experience construct and the reliability of the two data collection methods it is also necessary to ascertain the representativeness of the subgroup employing the ESM. Comparison of the mean mood and involvement scores on the entry form of the RES between ESM and non-ESM students found no significant differences with either variable. However, on the exit form of the RES, mean involvement ratings were higher for ESM students (m=1.94) than for non-ESM students (m=1.39, $t_{(78)}$=-2.57, p<.05). No differences were found between mean enjoyment ratings. Because the difference between groups did not emerge until after the program, it appears that participation in the experience sampling study increases perceptions of involvement.

Relationship of Subjective Experience to Perceived Skills and Challenges

According to flow theory experience becomes more entropic (less ordered, more negative) when the opportunity for action exceeds a person's perceived capabilities or doesn't allow the person to make full use of their skills. Furthermore, experience is more negentropic (more orderly and positive) for activities in which students perceive themselves to be more highly skilled. A hypothetical three-dimensional model illustrating the anticipated variations in subjective experience as a function of perceived skills and challenges is shown in Figure 1.

In order to determine how the quality of experience relates to perceived skills and challenges, ESM data was used to construct two 3 by 3 matrices representing enjoyment and involvement ratings by students whose self-perceived skill level is *below average* ($z_{SKILL} < -0.43$), *average* ($z_{SKILL} > -0.43$ and $z_{SKILL} < 0.43$), or *above average* ($z_{SKILL} > 0.43$) during activities that are perceived to be *not challenging enough*, *just right*, or *too challenging*. As described earlier, all ESM variables, except for the challenge rating, have been standardized at the individual level. Table 4 presents the mean ESM enjoyment and involvement ratings by perceived skill level and challenge level. The ESM data from Table 4 is also presented as three-dimensional line graphs in Figures 2 and 3.

Given the above findings several points can be made about the relationship between the quality of the students' experience during the apprenticeship and their perceived levels of skills and challenges. Quality of experience varies widely and systematically as a function of perceived skills and challenges. The highest quality experiences are found in the high skill/appropriate challenge condition and the lowest quality experiences are found in the low skill/inappropriate challenge conditions. These findings provide support for the central conception of flow theory. The concept of flow, consequently, will prove to be a useful interpretive framework for evaluating the various components of the apprenticeship program.

Figure 1

Hypothetical 3-D Line Graph Showing Quality of Experience as a Function of Skill and Challenge

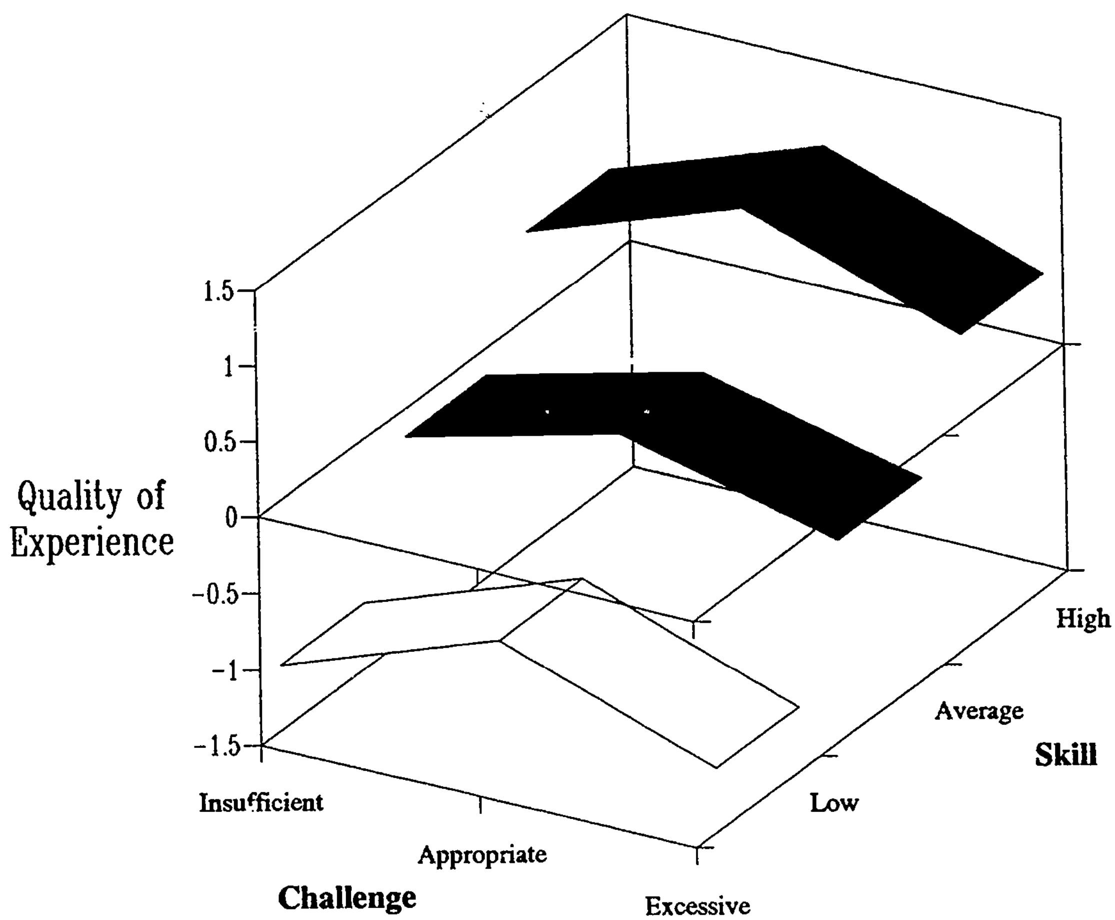


TABLE 4

MEAN ESM ENJOYMENT AND INVOLVEMENT RATINGS
BY SKILL LEVEL AND CHALLENGE LEVEL

	Challenge		
Skills:	too low	just right	too high
	Enjoyment		
High	0.23 (n=112)	.33 (85)	.30 (43)
Average	-0.04 (68)	0.03 (200)	-0.17 (50)
Low	-0.40 (41)	-0.16 (139)	-0.48 (42)
	Involvement		
High	0.12 (n=112)	0.29 (n=85)	0.17 (44)
Average	0.04 (67)	0.05 (198)	-0.07 (49)
Low	-0.25 (40)	-0.16 (138)	-0.48 (43)

Gender and Ethnicity Comparisons

In order to determine whether differences in the quality of experience during the program exist between under- and over-represented groups of students, the two-way ANOVA was used. The two main effects used in the analyses were gender (male, female) and ethnicity (Asian, Black, Caucasian). There were too few Hispanics in the sample to include them in the analysis. ANOVA tests were conducted with the two

Figure 2

3-D Line Graph Showing Mean Enjoyment Ratings as a Function of Skill and Challenge

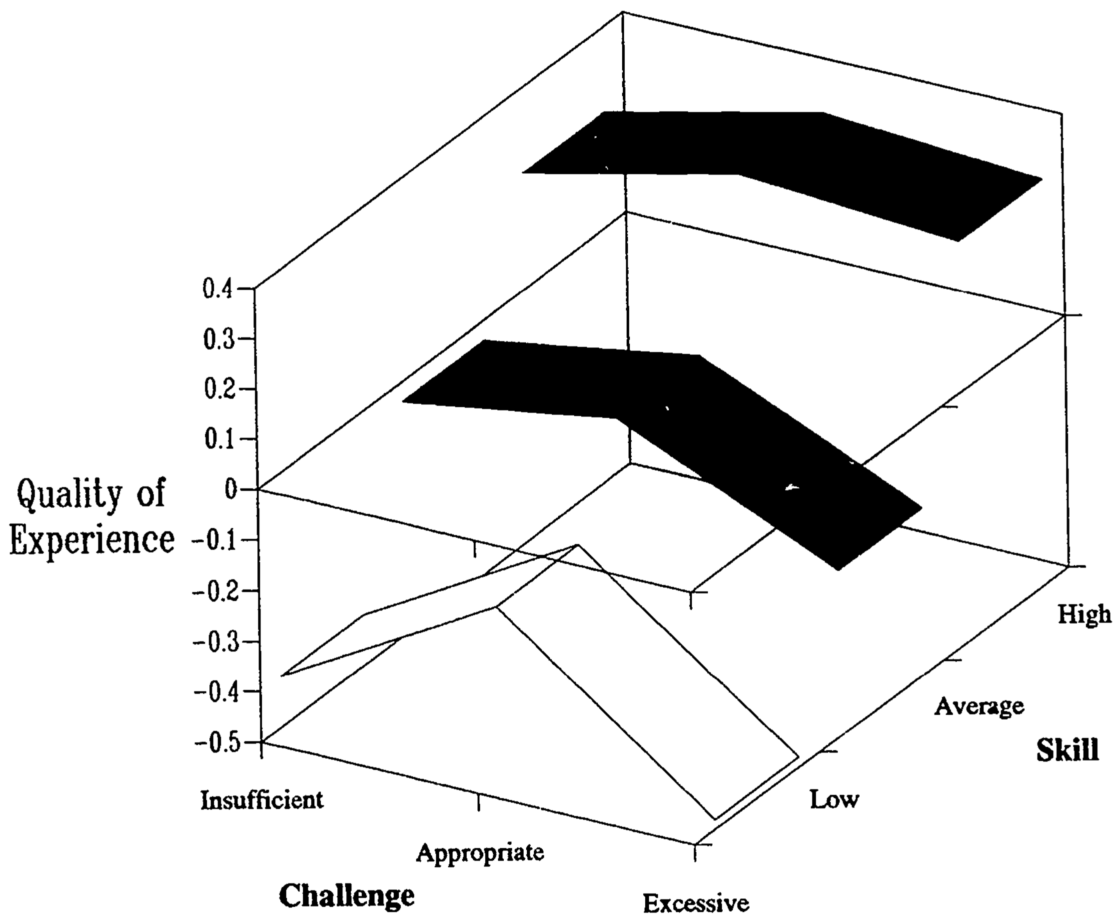
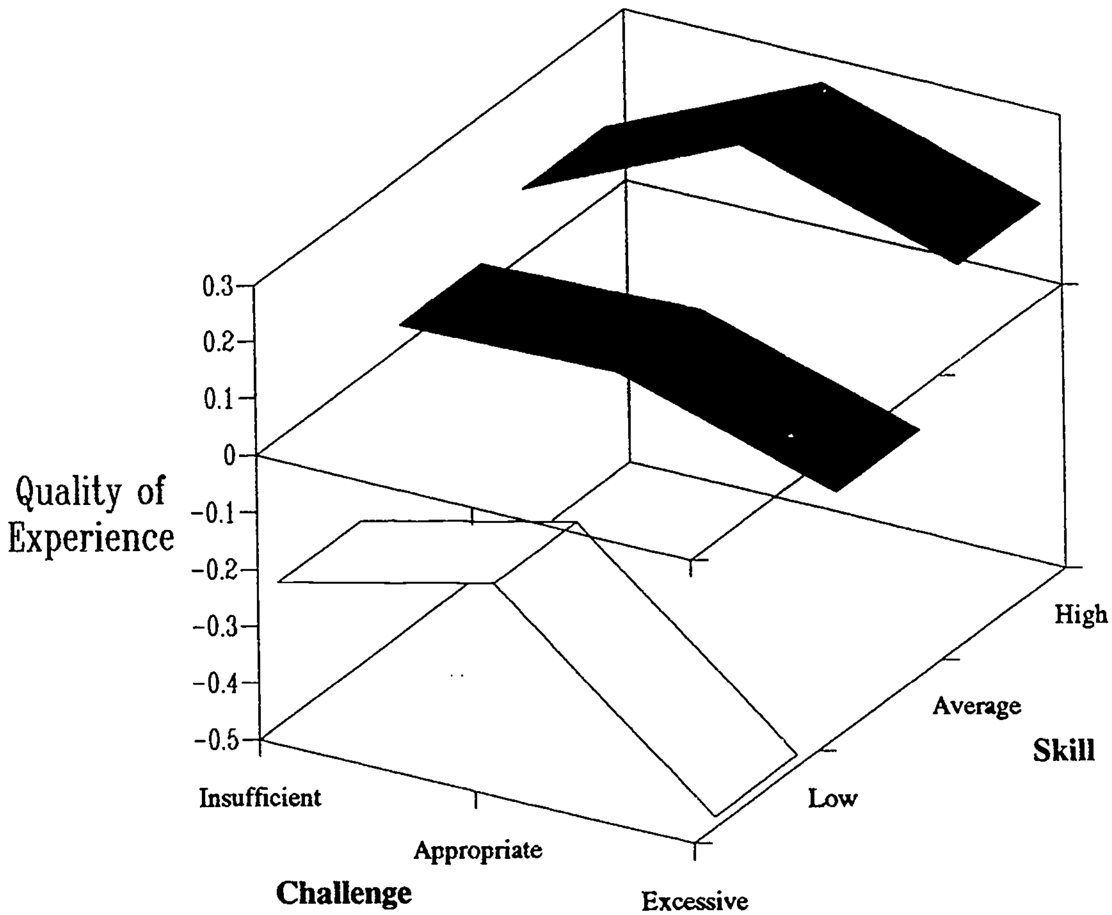


Figure 3

3-D Line Graph Showing Mean Involvement Ratings as a Function of Skill and Challenge



dimensions of experience -- enjoyment and involvement, and the two characteristics of flow situations -- skills and challenges.

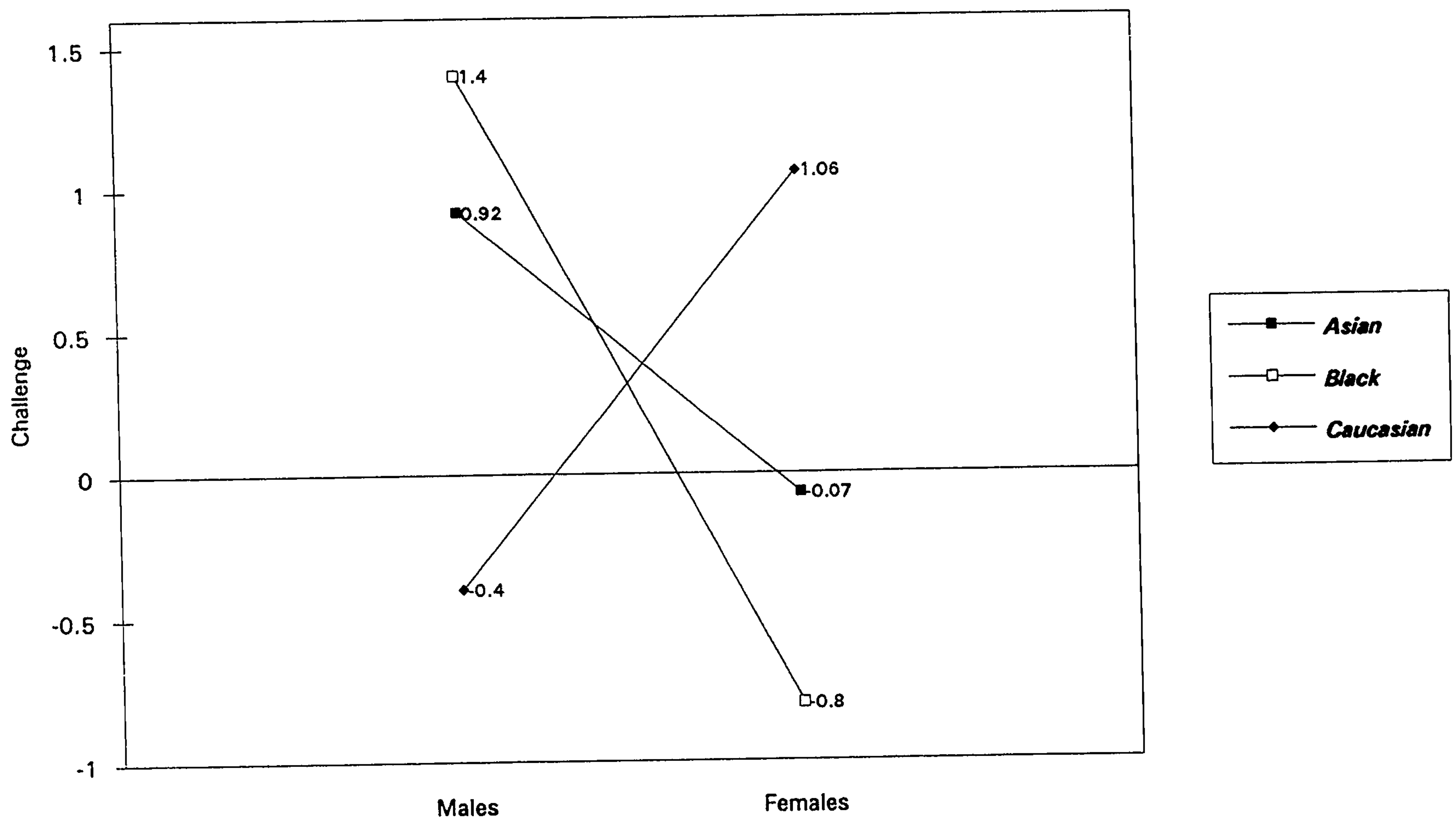
The results from the ANOVA comparisons revealed just one difference that was significant at the .05 level. A gender by ethnicity interaction occurred with the perceived challenges variable ($F_{(2,67)} = 7.72, p<.01$). The Tukey-Kramer modification of the HSD test was used to compare each of the cell means to one another. The results revealed a significant difference between Black male and female students. Black males perceived the research apprenticeship be excessively challenging to a greater extent than any other group (M = 1.4), whereas Black females perceived the research apprenticeship to be insufficiently challenging to a greater extent than any other group (M = -.80). Mean challenge ratings for the six groups are shown in Figure 4.

Quality of Experience During the Argonne Research Apprenticeship

In order to determine which aspects of the apprenticeship program provided the highest quality experiences, four comparisons of activity domain were made using the experience sampling data. First, the quality of experience was compared for three broad program areas: (1) laboratory activities, (2) lectures, and (3) miscellaneous. Comparisons were also made within each of the broad program areas. Thus, the quality of experience was compared among the five laboratory sessions, among the nine lectures, and among the six miscellaneous activity domains. The miscellaneous category encompassed the following activity domains: (a) tours of Argonne facilities, (b) tour of the University of Chicago, (c) safety orientation, (d) routine business, (e) lunch and other unstructured social activities, and (f) transitions.

Because the number of experience sampling reports in any given category varies from student to student, mean enjoyment and involvement z-scores were computed for each subject for each activity domain. Each of the four multivariate analyses of variance tests applies a two factor factorial repeated measures design. The first factor is activity

Figure 4
Gender by Ethnicity Interaction for Challenge Level



domain. The second factor is dimension of experience (enjoyment and involvement). The decision to adopt a two factor multivariate design was based on the high correlation between enjoyment and involvement ratings.

Mean experience ratings by program area are presented in Figure 5. The analysis revealed four differences, significant at the .05 level: there was a significant activity domain by experience dimension interaction for the broad program area comparison, a dimension of experience effect for the laboratory sessions comparison, and an activity domain effect for both the laboratory session and lecture comparisons. Table 5 provides a summary of the analysis of variance results.

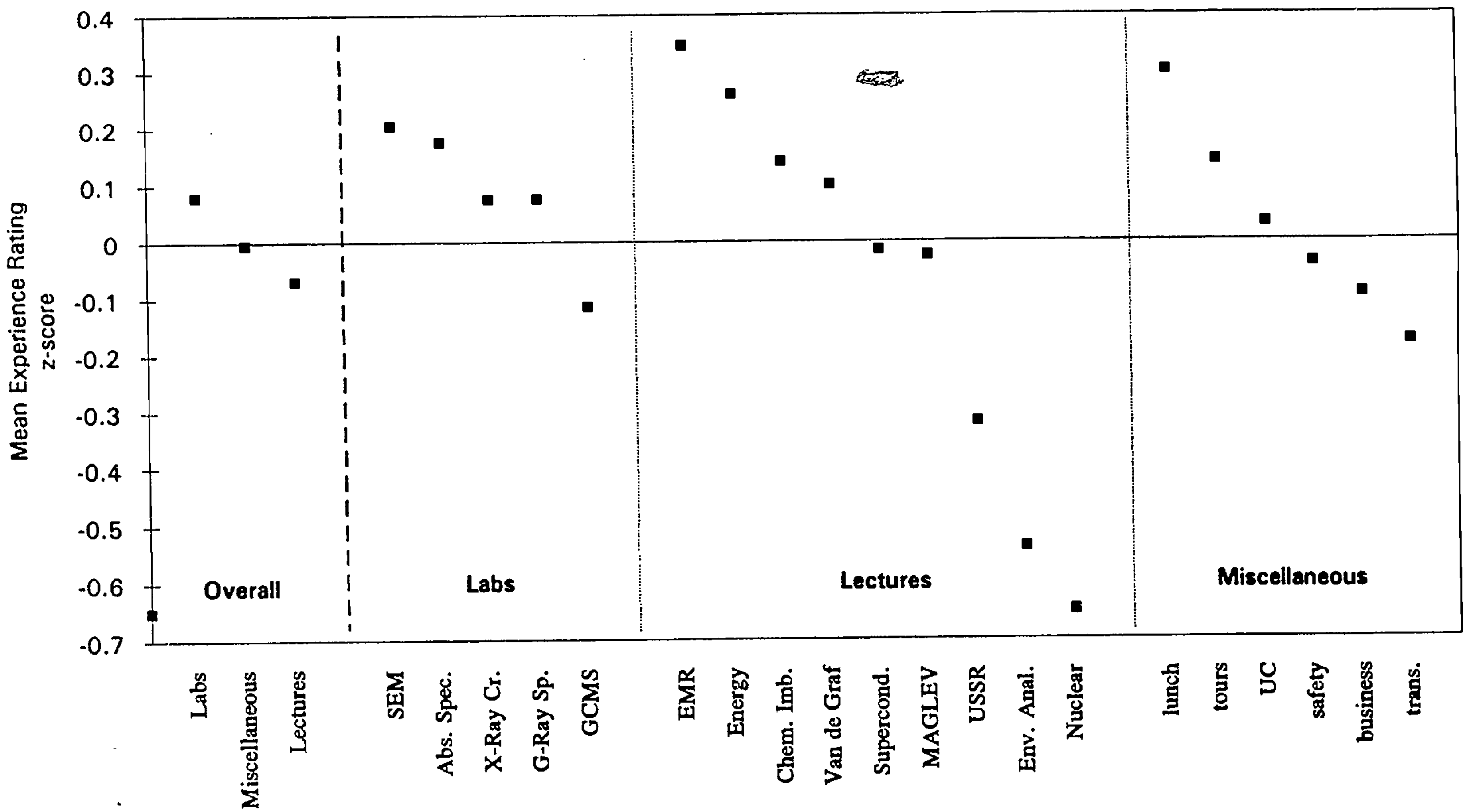
TABLE 5

SIGNIFICANT COMPARISONS BETWEEN ACTIVITY DOMAIN AND DIMENSION OF EXPERIENCE

	Broad Program Area	Laboratory Sessions	Lectures	Miscellaneous
Activity Domain	N.S.	$p<.05$	$p<.001$	N.S.
Experience Dimension	N.S.	$p<.05$	N.S.	$p<.01$.
Activity Domain by Experience Dimension	$p<.01$	N.S.	$p<.01$	N.S.

The broad program area comparison resulted in a significant activity domain by experience dimension interaction ($F_{(2,30)}=6.67$). The interaction effect is due to a unique pattern of experience within the miscellaneous program areas in which enjoyment ($M=.09$) was rated significantly higher than involvement ($M = -.10$, $F_{(1,15)} = 13.34$). The opposite pattern of experience was evident in the laboratory domain ($M_{enjoyment} = .05$, $M_{involvement} = .11$, $F_{(1,15)} = 5.01$). Enjoyment and involvement ratings were both rated

Figure 5
Quality of Experience During Apprenticeship Activities



below average in the lecture domain ($M_{enjoyment}$ = -.10, $M_{involvement}$ = -.04). Mean experience ratings for the six groups are shown in Figure 6.

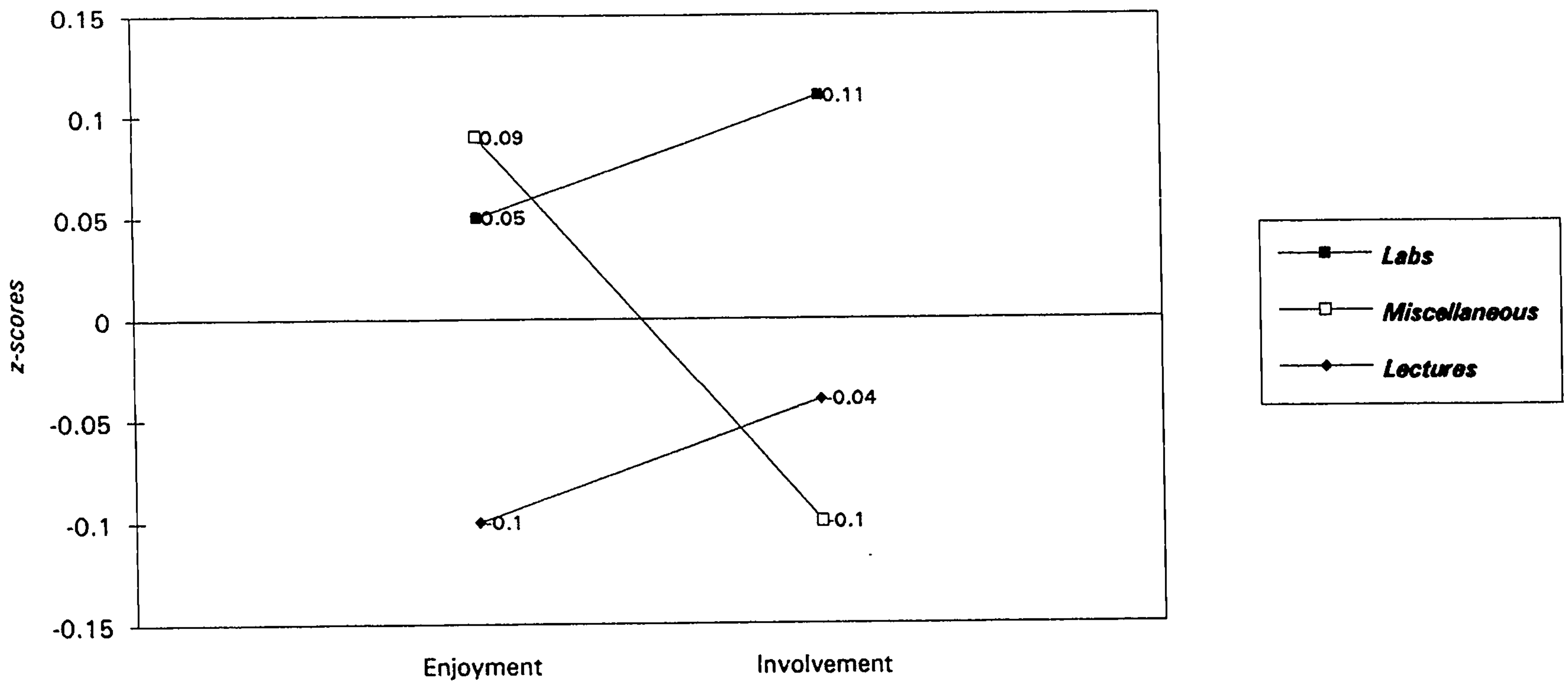
How well are you concentrating? appears to be the item contributing most to the relatively low involvement ratings in the miscellaneous activity domain (*M* = .28). For the miscellaneous enjoyment ratings, the four pairs of emotion terms, *joyful / distressed* (*M* = .21), *appreciative / resentful* (*M* = -.18), *pleased / angry* (*M* = .17), and *excited / afraid* (*M* = -.16), stand out for their high ratings.

How well are you concentrating? is also the item contributing most to the high involvement ratings during laboratory sessions (M = .11). The word pair *appreciative / resentful* (*M* = -.10) stands out as being the lowest rated item from the enjoyment scale during laboratory activities.

In the comparison focusing on laboratories , significant differences were found in the quality of experience during particular laboratory activities ($F_{(4,60)}$ = 2.65). As shown in figure 5, the gas chromatography / mass spectroscopy (GC/MS) laboratory received exceptionally low experience ratings (M = -.15). The items from the experience sampling form providing the lowest ratings for the GC/MS lab were the word pair *clear / confused* (*M* = -.46), and the items *Do you wish you were doing something else?* (*M* = -.36), and *How hard is it to concentrate?* (*M* = -.35).

A significant interaction emerged in the comparison focusing on lectures ($F_{(8,120)}$ = 5.16). Figure 7 reveals several interesting patterns of experience during various lectures. Only the Electromagnetic Radiation lecture was rated highly on both enjoyment and involvement. Three lectures (Nuclear Energy, Environmental Analysis, and Education in the Former U.S.S.R) received low ratings on both enjoyment and involvement. Three lectures showed a pattern in which involvement levels were higher than enjoyment levels (Energy Transformations, Chemical Imbalances, and Van De Graf Generator). Two lectures (Superconductivity, and Magnetic Levitation) showed the opposite pattern -- enjoyment levels surpassing involvement levels.

Figure 6
Dimension of Experience by Broad Program Area Interaction



The main effect for activity domain was also significant in the lecture comparison ($F_{(8,120)}$ = 9.37). Post hoc analysis using Tuckey's HSD test showed that the difference was attributable to exceptionally low experience ratings for the Nuclear Energy lecture (M = -.65) and the Environmental Analysis lecture (M = -.54). The items on the experience sampling form that received the lowest ratings during the Environmental Analysis lecture were the word pairs *involved / detached* (M = -.79) and *active / passive* (-.77). The item *creative / dull* received an exceptionally low mean rating during the Nuclear Energy lecture (M = -1.08).

Flow During the Argonne Research Apprenticeship

In order to determine whether certain aspects of the apprenticeship program were more or less conducive to flow, boredom, anxiety, and apathy, chi-square tests of independence were conducted. The Pearson chi-square was calculated using ESM data at the signal level, meaning each experience sampling report was treated as an independent observation. For each observation, a classification of flow, boredom, anxiety, or apathy was made on the basis of the skills and challenges ratings. Observations, in which the student's skills in the activity were rated above average ($z_{SKILL} > 0$, standardized at the individual level) and the level of challenge was rated *just right*, were classified into the flow condition. Observations in which the level of challenge was perceived to be insufficient were classified into the boredom condition. When the level of challenge was excessive, observations were classified into the anxiety condition. When the challenge level was *just right* but the skill level was below average, observations were classified into the apathy condition. To maintain consistency with the quality of experience comparisons, four contingency tables will be constructed using activity domain as an independent variable. Thus activity domain will be categorized by broad program area, by laboratory session, by lecture, and by miscellaneous activity domain.

Table 6 shows the frequencies of flow, boredom, anxiety, and apathy for the three broad program areas. The observed frequency distribution shows that the skill/challenge condition is independent of the broad program area ($\chi^2_{(6,N=605)} = 18.80$, $p<.05$). The miscellaneous activity domain stands out for having relatively few observations meeting the anxiety condition. Laboratory activities, on the other hand, show a higher than expected frequency of anxiety observations, but relatively few apathy observations. Lectures are observed to be conducive to the apathy condition but inhibiting to the flow condition.

TABLE 6

FREQUENCIES OF OBSERVED FLOW, BOREDOM, ANXIETY, AND APATHY BY BROAD PROGRAM AREA

	Flow	Boredom	Anxiety	Apathy
Laboratories	46 (17.8%)	66 (25.6)	60 (23.3)	86 (33.3)
Lectures	13 (9.8)	44 (33.3)	18 (13.6)	57 (43.2)
Miscellaneous	32 (14.9)	68 (31.6)	26 (12.1)	89 (41.4)
Overall	91 (15.0)	178 (29.4)	104 (17.2)	232 (38.3)

Note: Numbers in parentheses are row percentages.

Table 7 shows the frequencies of flow, boredom, anxiety, and apathy for the five laboratory activities. The observed frequency distribution indicates that the skill/challenge condition is independent of the broad program area ($\chi^2_{(12,N=258)} = 30.38$, $p<.01$). A higher than expected frequency of apathy observations stands out for Absorption Spectroscopy lab. A relatively low incidence of apathy occurs in the X-Ray

Crystallography lab. The Gas Chromatography/Mass Spectroscopy lab appears to produce a high degree of frustration and the Scanning Electron Microscope (SEM) lab a low degree of frustration. The SEM lab, however, tends to promote boredom. Observations of the flow condition appear to be fairly evenly distributed among the five laboratory activities.

TABLE 7

FREQUENCIES OF OBSERVED FLOW, BOREDOM, ANXIETY, AND APATHY BY LABORATORY SESSION

	Flow	Boredom	Anxiety	Apathy
Gamma Ray Spectroscopy	7 (14.6%)	9 (18.8)	13 (27.1)	19 (39.6)
Scanning Electron Microscope	9 (17.3)	19 (36.5)	4 (7.7)	20 (38.5)
X-Ray Crystallography	11 (21.6)	17 (33.3)	14 (27.5)	9 (17.6)
Gas Chromatography / Mass Spectroscopy	10 (18.2)	9 (16.4)	22 (40.0)	14 (25.5)
Absorption Spectroscopy	9 (17.3)	12 (23.1)	7 (13.5)	24 (46.2)
Total	46 (17.8)	66 (25.6)	60 (23.3)	86 (33.3)

Note: Numbers in parentheses are row percentages.

Many of the cell sizes in the skill/challenge condition by lecture contingency table (Table 8) are too small to permit a chi-square test to be conducted. However, a few atypical proportions in the table are worth noting. A high incidence of apathy was observed in the Chemical Imbalances in the Human Brain lecture. A high degree of boredom occurred in the Magnetic Levitation lecture. And the lecture on

TABLE 8

FREQUENCIES OF OBSERVED FLOW, BOREDOM, ANXIETY, AND APATHY BY LECTURE

	Flow	Boredom	Anxiety	Apathy
Energy Transformations	0	4 (33.3%)	4 (33.3)	4 (33.3)
Nuclear Power	1 (7.1)	7 (50.0)	2 (14.3)	4 (28.6)
School in former USSR.	2 (12.5)	4 (25.0)	2 (12.5)	8 (50.0)
Environmental Analysis	2 (13.3)	6 (40.0)	2 (13.3)	5 (33.3)
Superconductivity	1 (6.3)	6 (37.5)	1 (6.3)	8 (50.0)
Van De Graf Generator	0	5 (38.5)	2 (15.4)	6 (46.2)
Magnetic Levitation	2 (18.2)	6 (54.5)	0	3 (27.3)
Chemical Imbalances	3 (13.6)	2 (9.1)	1 (4.5)	16 (72.7)
EM Radiation	2 (15.4)	4 (30.8)	4 (30.8)	3 (23.1)
Total	13 (9.8)	44 (33.3)	18 (13.6)	57 (43.2)

Note: Numbers in parentheses are row percentages.

Electromagnetic Radiation was notable for promoting a high frustration level and a low apathy level. However, to formulate any conclusions based on such a small number of observations would be presumptuous.

Small cell sizes also prohibited the use of the chi-square test with the skill/challenge condition by miscellaneous activity domain contingency table (Table 9).

TABLE 9

FREQUENCIES OF OBSERVED FLOW, BOREDOM, ANXIETY, AND APATHY BY MISCELLANEOUS ACTIVITY DOMAIN

	Flow	Boredom	Anxiety	Apathy
Transition	14 (18.4%)	20 (26.3)	14 (18.4)	28 (36.8)
Argonne Tours	2 (9.1)	11 (50.0)	1 (4.5)	8 (36.4)
Routine Business	1 (11.1)	3 (33.3)	0	5 (55.6)
Lunch and Free Time	10 (22.2)	9 (20.0)	4 (8.9)	22 48.9)
Safety Orientation	1 (4.2)	13 (54.2)	2 (8.3)	8 (33.3)
University of Chicago	4 (10.3)	12 (30.8)	5 (12.8)	18 (46.2)
Total	32 (14.9)	68 (31.6)	26 (12.1)	89 (41.4)

Note: Numbers in parentheses are row percentages.

Nevertheless, a higher than expected incidence of boredom occurred during the safety orientation and Argonne tours. On the other hand, lunch and other unstructured activities appear to discourage boredom.

Discussion

This study explores the subjective experiences of academically talented high school sophomores attending a summer science apprenticeship program at a Department of Energy Laboratory. Because it cannot be claimed that the sample is representative of all high school science students, this study is descriptive. The value of the study lies in its data collection method and theoretical foundation. The discussion below addresses the findings of the study as they pertain to the flow theory of intrinsic motivation.

A robust body of empirical research on the theory of flow has demonstrated that an important contributor to personal growth in a particular field of endeavor is the quality of an individual's experience in that field. The evidence strongly supports the contention that quality of experience is optimized in those situations where an individual feels highly capable and the opportunities for action are neither excessive or insufficient.

Subjective experience was shown in this study to be composed of two distinct factors -- enjoyment and involvement. This finding suggests that previous research on flow theory may have adopted a three factor taxonomy of subjective experience unnecessarily. Csikszentmihalyi cites Hilgard's (1980) trilogy of mind theory to support his classification of subjective experience into mood, cognitive efficiency, and motivation dimensions. Except for a factor analysis of the mood items into activation and emotion components (Mayers, 1978) very little statistical verification of this classification has been attempted. Although Hilgard's tridimensional theory of mind may have provided a useful framework for developing the experience sampling questionnaire, the value of distinguishing between cognitive and motivation variables has been statistically marginal. The two variable clusters are highly correlated and behave almost identically in the rare experience sampling study that examines them as clusters (Massimini, Csikszentmihalyi, & Carli, 1987).

The most important findings of the experience sampling method evaluation are:

1. Black male and Caucasian female students are more likely than other groups to perceive the research apprenticeship to be excessively challenging; Black females are the only group to perceive insufficient challenges in the apprenticeship. Although there were only 5 Black males in the sample, it, nevertheless, seems plausible that Black males and Caucasian females, being underrepresented in science-related occupations, could be uniquely sensitive to excessive levels of challenge in an educational science setting.

However, the fact that the trend among Asian males and females (i.e., greater anxiety in females and greater boredom in males) was more like that among Black students than Caucasian students suggests that more than simple under-representativeness is at issue. Cultural factors are clearly a factor. The extreme lack of challenge perceived by Black females during the apprenticeship program is unexpected and difficult to explain. Parental expectations, role models, and peer support are the most likely factors in the gender difference among Black student participants. .

2. Enjoyment levels are highest during unstructured apprenticeship activities such as lunch, recreation, and tours; levels of involvement were highest during laboratory activities. Despite high correlations between reported levels of enjoyment and involvement, the relationship between the two dimensions of experience, nevertheless, is largely determined by circumstantial function and relevance. Higher levels of involvement relative to enjoyment occur in situations that are likely to contribute to the establishment of adult roles. Conversely, higher relative levels of enjoyment are indicative of situations in which childhood roles are maintained and peer relationships predominate.

3. Lecture activities minimize the potential for students to experience flow (high skills / appropriate challenges); laboratory activities minimize the potential for students to experience boredom (insufficient challenges) and apathy (low skills / appropriate challenges). This result is consistent with the idea that learning experiences providing the greatest opportunity for creativity and freedom are perceived by the learner to be the most rewarding. According to informal student interviews, the Gas Chromatography/Mass Spectroscopy lab, which provided a uniquely low quality experience was also the most rigidly structured laboratory session. The opportunity for hands on activity is another characteristic aspect of laboratory, as opposed to lecture, activities. Flow experiences require the opportunity for an individual's skills to be applied. However, abstract thinking is not a highly developed skill in the vast majority

of high school sophomores. Nevertheless, according to student interviews, those lecturers who attempted to increase student involvement during their presentations through the use of questioning, demonstrations, and meaningful examples were generally sucessful in providing a higher quality experience for the students..

Apprenticeships and other experiential learning models are receiving increasing attention among educational reformers. Additional information is needed on which learning formats and instructional procedures foster intrinsic motivation. Because the relationship between quality of experience and skill development is reciprocal, it is crucial that positive experiences with science be provided before critical decisions are made about educational and career options. Future research should overcome two limitations of the present study by examining the specific features of various instructional practices that promote or inhibit positive learning experiences and by validating the self report findings with more objective assessments.

References

Argonne National Laboratory, Division of Educational Programs (1980). Report on the 1980 Summer Research Apprenticeship Program. Argonne, IL: Argonne National Laboratory, Division of Educational Programs

Brandwein, Paul (1986). A portrait of gifted young with science talent. Roeper Review,8(4), 235-243.

Cody, John T. & Pizzini, Edward L. (1976). The effects of a secondary science training program on the methods, procedures, and processes of science. Science Education, 60(2), 193-198.

Collins, A., Brown, J. S., & Newman, S. E. (1989). Cognitive apprenticeship: Teachng the craft of reading, writing, and mathematics. In L. B. Resnick (Ed.), Knowing, Learning, and Instruction: Essays in Honor of Robert Glaser. Hillsdale, NJ: Lawrence Erlbaum Associates, pp. 453-494.

Csikszentmihalyi, M. (1975). Beyond Boredom and Anxiety: The Experience of Play in Work and Games. San Francisco: Jossey-Bass.

Csikszentmihalyi, M. (1978). Intrinsic reward and emerging motivation. In M. R. Lepper and D. Greene (Eds.), The Hidden Cost of Reward. New York: Erlbaum, 1978.

Csikszentmihalyi, M. (1982a). Toward a psychology of optimal experience. In L. Wheeler (Ed.), Review of Personality and social Psychology (Vol. 2). Beverly Hills, CA: Sage.

Csikszentmihalyi, M. (1982b). Education and life-long learning. In R. Gross (Ed.), Invitation to Life-Long Learning, (pp. 167-187). New York: Fowlett.

Csikszentmihalyi, M. (1988). The flow experience and its significance for human psycholcgy, (pp. 15-35). In M. Csikszentmihalyi and I. S. Csikszentmihalyi (Eds.), Optimal Experience: Psychological Studies of Flow in Consciousness, . New York: Cambridge University Presss.

Csikszentmihalyi, M. (1990). Flow: The Psychology of Optimal Experience. New York: Harper & Row.

Csikszentmihalyi, M. & Larson, R. (1984). Being Adolescent: Conflict and Growth in the Teenage Years. New York: Basic Books.

Csikszentmihalyi, M., Larson, R., & Prescott (1977). The ecology of adolescent activity and experience. Journal of Youth and Adolescence, 6, 281-294.

Hawkins, Jan & Pea, Roy D. (1987). Tools for bridging the cultures of everyday and scientific thinking. Journal of research in Science Teaching, 24(4), 291-307.

Larson, R. & Richards, M. H. (1989). Introduction: The changing life space of early adolescence. Journal of Youth and Adolescence, 18(6), 501-509.

LeFevre, J. (1988). Flow and the quality of experience during work and leisure, (pp. 307-318). In M. Csikszentmihalyi and I. S. Csikszentmihalyi (Eds.), Optimal Experience: Psychological Studies of Flow in Consciousness, . New York: Cambridge University Press.

Massimini, F. & Carli, M. (1988). The systematic assessment of flow in daily experience. In M. Csikszentmihalyi and I. S. Csikszentmihalyi (Eds.). Optimal Experience: Psychological Studies of Flow in Consciousness, (pp. 266-287). New York: Cambridge University Press.

Massimini, F., Csikszentmihalyi, M., & Carli, M. (1987). The monitoring of optimal experience: A tool for psychiatric rehabilitation. Journal of Mental and Nervous Disease, 175, 545-549.

Roth, Wolff-Michael & Roychoudhury, Anita (1992). The social constructionof scientific concepts or the concept map as conscription device and tool for social thinking in high school science. Science Education, 76(5), 531-557.

Smith, Edward L. (1991). A conceptual change model of learning science. In S. M. Glynn, R. H. Yeany, & B. K. Britton (Eds.), The Psychology of Learning Science, pp. 43-64. Hillsdale, NJ: Lawrence Erlbaum Associates.

Treagust, D. F. & Cody, J. (1977). Biochemistry for secondary students. The American Biology Teacher, 39, 132-134.

APPENDIX A

Experience Sampling Form

Date: ________ Time Beeped: ________ am pm Time Filled Out: ________

As you were beeped . . .

What were you thinking? ____________________

____

Where were you? (if in lab specify which one) ____________________

____

What was the main thing you were doing? ____________________

____

Describe your experience of the main activity:

	not at all									very much
How well were you concentrating?	0	1	2	3	4	5	6	7	8	9
Was it hard to concentrate?	0	1	2	3	4	5	6	7	8	9
Did you wish you had been doing something else?	0	1	2	3	4	5	6	7	8	9
Was this activity interesting?	0	1	2	3	4	5	6	7	8	9
Was this activity important to you?	0	1	2	3	4	5	6	7	8	9
How important was it in relation to your future goals?	0	1	2	3	4	5	6	7	8	9

— — — — — — — — — — — — — — — — — — — —

Describe your mood as you were beeped:

	very	quite	some	neither	some	quite	very	
Involved	0	o	.	-	.	o	0	Detached
Clear	0	o	.	-	.	o	0	Confused
Tired	0	o	.	-	.	o	0	Energetic
Angry	0	o	.	-	.	o	0	Pleased
Passive	0	o	.	-	.	o	0	Active
Dull	0	o	.	-	.	o	0	Creative
Afraid	0	o	.	-	.	o	0	Excited
Joyful	0	o	.	-	.	o	0	Distressed
Resentful	0	o	.	-	.	o	0	Appreciative

45

APPENDIX A (continued)

Experience Sampling Form

Skills and Challenges:

How skilled are you in the main activity? (Compared to the average person)

less skilled				average				more skilled
-4	-3	-2-	-1	0	+1	+2	+3	+4

How challenging is the main activity for you?

not challenging enough				just right				too challenging
-4	-3	-2-	-1	0	+1	+2	+3	+4

— —

Express yourself: Brilliant thoughts, ideas, complaints, excuses, jokes, drawings . . .

APPENDIX B

Sample Randomized Alarm Schedule

Activity	Interval	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8
Lecture	08:30 – 09:30	09:23	09:23	09:04	09:25	08:33	09:12	09:16	08:54
Morning Lab	10:00 – 12:30	11:24 11:02	11:25 10:03	10:46 11:44	11:58 10:58	11:14 11:49	10:17 11:47	11:34 12:14	10:23 11:31
Afternoon Lab	13:30 – 16:00	13:46 14:37	14:37 13:40	14:08 13:39	14:37 15:05	15:34 14:53	13:34 14:33	15:03 14:21	13:42 15:11
Unstructured	07:30 – 08:30; 09:30 – 10:00; 12:30 – 13:30; 16:00 – 22:30;	19:48 16:17	20:03 20:32	18:56 21:10	19:02 22:02	07:46 19:15 08:01	20:27 22:23 21:19	22:38 19:19	09:56 16:43
	weekend 08:30 – 23:30	Sat. 15:45	Sun. 16:21	Sun. 12:42	Sun. 13:50			Sat. 21:59	Sat. 22:57

APPENDIX C

Retrospective Experience Survey

1. Most of the time while you were at Argonne . . .

	not at all									very much
How well did you concentrate?	0	1	2	3	4	5	6	7	8	9
Was it hard to concentrate?	0	1	2	3	4	5	6	7	8	9
Did you wish you had been doing something else?	0	1	2	3	4	5	6	7	8	9
Were the activities interesting?	0	1	2	3	4	5	6	7	8	9
Were the activities important to you?	0	1	2	3	4	5	6	7	8	9
How important were they in relation to your future goals?	0	1	2	3	4	5	6	7	8	9

2. Indicate how you usually felt at Argonne:

	very	quite	some	neither	some	quite	very	
Involved	0	o	.	–	.	o	0	Detached
Clear	0	o	.	–	.	o	0	Confused
Tired	0	o	.	–	.	o	0	Energetic
Angry	0	o	.	–	.	o	0	Pleased
Passive	0	o	.	–	.	o	0	Active
Dull	0	o	.	–	.	o	0	Creative
Afraid	0	o	.	–	.	o	0	Excited
Joyful	0	o	.	–	.	o	0	Distressed
Resentful	0	o	.	–	.	o	0	Appreciative

3. Skills and Challenges:

How skilled are you in science? (Compared to the average person)

less skilled				average				more skilled
-4	-3	-2-	-1	0	+1	+2	+3	+4

How challenging was the Argonne Research Apprenticeship for you?

not challenging enough				just right				too challenging
-4	-3	-2-	-1	0	+1	+2	+3	+4