FINAL, TECHNICAL REPORT SCIENCE, ENGINEERING, AND MATHEMATICS (SEM) AT THE TIMBUKTU ACADEMY

Southern University and A&M College in Baton Rouge (SUBR), Louisiana

MATTER - ENERGY
FUNDAMENTAL
TIMBUKTU ACADEMY
1990
INTERACTION(S)
SPACE-TIME

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14. ABSTRACT
This publication is the final, technical report of Science, Engineering, and Mathematics (SEM) at the Timbuktu Academy, for the period of August 1998 to May 2005. It provides a thorough description of the design, programs, activities, and results of the Academy. The production of 108 minority college graduates in science, technology, engineering, and mathematics (STEM) disciplines, with 70 % of Physcs and Chemistry majors pursuing graduate degrees, with emphasis on the Ph.D., and the measurable enhancement of the pre-college preparation of over 800 students, in this reporting period, partly explain the reason Timbuktu Academy received the 2002 US Presidential Award for Excellence in Science, Mathematics, and Engineering Mentoring. Our 58 publications, 29 of which deal with teaching, mentoring, and learning, and our 177 presentations partly attest to our significant dissemination efforts. Selected publications, included in full in this report, provide a roadmap for the replication of our work, in cultivating academic excellence, and in closing acheivement graps, while adding significantly to the scientific knowledge.

15. SUBJECT TERMS
Systemic Mentoring; Power Law of Human Performance, Time on Tasks,; Achievement Gaps; Problem Solving Paradigm.
The Bagayoko, Zhao, and Williams Method for the ab-inito Calculations of Electronic and Related Properties of Materials.

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FINAL REPORT

GRANT#: N00014-98-1-0748

PRINCIPAL INVESTIGATOR: Diola Bagayoko, Ph.D., Southern University System Distinguished Professor of Physics and Director of the Timbuktu Academy, and Ella L. Kelley, Ph.D., Professor of Chemistry and Interim Chairperson

Program Officer, Office of Naval Research (ONR): **Laura Petonito, Ph.D**. (Up to 2003) and **Mr. William (Bill) Ellis** (from 2004 to Present)

INSTITUTION: Southern University and A & M College

GRANT TITLE: **Science, Engineering, and Mathematics (SEM) at the Timbuktu Academy**

AWARD PERIOD: August 1, 1998 – May 31, 2005

A BRIEF HISTORY: The Timbuktu Academy was first established in 1990-91, with funding from the National Science Foundation (NSF) and the Louisiana Board of Regents for the purpose of recruiting (Regents' funding) and mentoring (NSF funding) undergraduate physics majors. Twenty (20) Students were supported per year. Based on preliminary results, in student mentoring and in physics and educational knowledge production, a major funding was obtained from the Department of the Navy, Office of Naval Research (ONR) in 1993. This funding led to a vast expansion of the pre-college enrichment programs and to the mentoring of other science and engineering undergraduate students, besides the physics majors. From 1993 to 2000, fifty (50) science, technology, engineering, and mathematics students have been fully supported per year. This support provides for all costs associated with the matriculation (tuition and room and board) and research participation of these students; the systemic mentoring described below ensures that the full time job of a scholar is studying, enriching him/herself professionally, and conducting research. It enables the total academic and social integrations of the scholars, as per the prevailing retention models. From early 1990's to 2005, NASA supported 5-10 scholars of the Academy per year. The Hewlett Packard Company built the document production capabilities of the Academy with the donation of a professional, color printer ($10K), computers, and digital cameras. Each summer, federal, industrial, and university laboratories support the summer research of 30-50 Academy scholars. Bell Laboratory, the National Institute of Standards and Technology (NIST), Lawrence Livermore National Laboratory (LLNL) and other DOE laboratories (i.e., Argonne) and NASA field centers have been among the summer research sites of our scholars from the mid-1980's to present. The Louisiana Board of Regents funded the graduate component of the Academy, following the establishment of a Master's degree program in the Department of Physics in 1996 (based in part on the strength of the Academy).

Southern University and A&M College is located on the left bank of the mighty Mississippi River, at a point where it turns right; similarly, the City of Timbuktu, in Mali, West Africa, is located on the left banks of the majestic Niger River. Timbuktu, from the 14^{th} century to the end of the 16^{th} century (1591 exactly), was home to a group of universities, commonly called "the University of Timbuktu," that were bastions of scholarship in the middle of the second millennium. The name of the Timbuktu Academy is partly for dedicating ourselves to attaining and surpassing the intellectual exploits of the University of Timbuktu that had scholars (faculty and students) from most parts of the Mediterranean world, Europe, and Black Africa. Professors A. Baba and A. Bagayoko, both of whom were Black, are among the most celebrated scholars and mentors. The former was a student and mentee of the latter.

In June 2001, following written instructions from ONR, the Timbuktu Academy started a phase-down. This phase-down essentially consisted of continuing to support fully the scholars that were in the program while decreasing other costs (i.e., personnel) and not accepting any new scholars. This phase down continued until May 2004. Indeed, The Honorable Mary Landrieu, US Senator, provided the Navy with $1 Million through the US Congressional appropriation process. Consequently, from June 2002 to present, the Academy is operating under a new award (Grant No. N00014-4-1-0587). An additional amount of $1 Million is expected. Hence, the Academy continues to operate. Specifically, it is recruiting new undergraduate scholars, supporting them financially, and immersing them in its systemic mentoring environment; it also continues to provide summer academic enrichments for 100-200 pre-college students. Perhaps the area of greatest efforts, for the above new grant entitled "The Timbuktu Academy," is dissemination (through publications, presentations, conferences, workshops, the web, etc.) *to promote the replication of the Academy's scientific approach to (a) avoiding and (b) closing academic achievement gaps while enhancing the overall competitiveness of education (as per national norms).* In the above sense, the Timbuktu Academy has a national role and impact.

The following report partly reproduces and expands on the content of the 1993-98 Progress Report relative to the approach, paradigm, programs, objectives, and some related issues. While the summative results encompass those of 1993-98, detailed, numeric tables at the web site of the Academy (and available from the director) provide the pre-college and college student outcomes *year by year*. The list of publications only contains the ones from 1999 to 2005. The same is true for the awards. With the above understanding, the rest of this final report follows.

OBJECTIVE: As per the proposal funded by the Department of the Navy, Office of Naval Research (ONR), the objectives of Science, Engineering, and Mathematics (SEM) at the Timbuktu Academy are **(a)** to produce well-trained Bachelor degree holders in Science, Engineering, and Mathematics (SEM) and to produce new knowledge at the Timbuktu Academy—fifty (50) undergraduate students are to be supported per year; **(b)** to guide a significant percent of these graduates, beyond the average percentages per disciplines, to the successful pursuit of advanced degree programs in science, mathematics, and engineering (SEM) disciplines and related ones, with emphasis on the

Ph.D. degree; and **(c)** to deliver extensive, educational services to 5000 pre-college and college students, their teachers, counselors, parents, and to members of the larger community.

APPROACH: The essential characteristics of our approach are listed below. **(1)** We have established, through research and publication, *a paradigm for the creation of educational, research, and professional value-added.* This paradigm, known as the Paradigm of the Timbuktu Academy, rests on a current, dynamic sum of knowledge in education and related disciplines, including cognitive and behavioral sciences. **(2)** This paradigm was utilized to design programs and activities. It led to the unavoidable concept of "distributed responsibilities and shared credits (DRSC)" explained at our web site. It also led to *defining systemic mentoring and to placing it on a rigorous scientific basis* [Education, Vol. 115, No. 1, pp. 31-39, pp.11-18 (1994)]. **(3)** Our implementation of the systemic mentoring activities, including research participation for undergraduates, and the academic enrichment activities for pre-college students have strictly adhered to the paradigm that has guided them. The details of the paradigm, programs, activities, and results (including some publications) of the Timbuktu Academy are available at its web site **(http://www.phys.subr.edu/timbuktu.htm). (4)** In particular, the following subprograms are described at the web site of the Academy: **(P1)** Getting Smarter at the Timbuktu Academy (GeSTA), for 20 elementary school students; **(P2 & P3)** Summer Science Institutes (SSI-M and SSI) for twenty to forty (20-40) middle school and for twenty (20) 11th grade, high school students, respectively; **(P4)** Summer Enrichment at the Timbuktu Academy (SETA), for 20 rising ninth graders; **(P5)** Challenge 2000 for twenty (20-40) high school students *of various classifications and academic preparation*, to simulate reality in many American high school classrooms; **(P6)** the Summer Bridge Institute (SBI), an early college enrollment program for twenty (20) high-achieving, high school graduates; **(P7)** *the Undergraduate Research Program (URP) for college students in science, engineering, and mathematics, these students numbered at least fifty (50) per year, before the phase-down*; **(P8)** Graduate Research Excellence at the Timbuktu Academy (GREAT, funded by Louisiana); and **(P9)** the Educational Service Program (ESP) that publishes extensively and disseminates *empowering, factual, educational knowledge to the larger community*. **(P10)** A year round Saturday Academy, also known as the *Learning Olympiads*, is a part of ESP; it includes preparation for some standardized exams and engaging pre-college students in stimulating, competitive learning activities (science bowls and quiz bowls). As discussed further at the web site and below, these programs *pay explicit attention to every transition point in the educational continuum*, i.e., elementary to middle, middle to high school, high school to college, undergraduate to graduate programs and beyond.

ACCOMPLISHMENTS (Emphasis on those from 1998 to 2003):

From inception to June 2004, 133 *minority undergraduate scholars of the Academy have earned a Bachelor's degree in a science or engineering field. Of the 74 physics, 26 chemistry, and 33 engineering graduates, 70%, 73%, and 39%, respectively, have earned or are currently pursuing graduate degrees, with emphasis on the Ph.D.* Thirty nine (39) of these alumni were produced in the first phase (1993-1998) and 94 were produced from 1998 to 2004 (i.e., this reporting period). The production rate has doubled in the second phase. Over 90% of these alumni are African American, even though the Academy is not restricted to them. Southern University is a Historically Black College and University (HBCU). One of our few Hispanic scholars, Mr. Billy Vegara, was the top graduate of SUBR in the spring of 1992. The Spring 2002, Fall 2003, Spring 2004, and Summer 2003 Student Grand Marshals (top of the graduating class) of SUBR were scholars of the Timbuktu Academy. More details are available on these alumni in the reprint of the 2004 Black Collegian feature article on the Academy. The orignal article is on the web (http://www.blackcollegian.com/issues/2ndsem05/timbuktu2005-2nd.shtml).

Gender Diversity was built into the program from the onset. Of the 74 Physics alumni, 39 are males and 35 are females; Of the 33 Engineering graduates, 19 are males and 14 are females. As for the 26 Chemistry graduates, eight (8) are males and 18 are females. A similar diversity pervades our pre-college and graduate programs. Unlike the undergraduate programs, several White students partook in the nationally known high school activities (SSI, Challenge 2000) from several states. Our publications and presentations further bring us close to ethnic diversity. National wide, the average gender distribution of undergraduates at many Historically Black Colleges and Universities, for the past five (5) years, has been 1.5-2 female for every male. The gender distribution of the alumni of the Timbuktu Academy is 1 to 1 (i.e., 66 Males and 67 Females).

The direct benefits to the Department of Defense partly stem from the fact that more than half of the physics alumni *who are not currently in graduate school* are in occupations directly related to Defense. *These eighteen (18) include eight (8) at Raytheon, three Navy officers, one National Security Agency (NSA) employee, and one Army employee.* The ones in graduate school or with graduate degrees, we trust, will benefit more sectors of the economy and society than we have space to speculate about here – *including sectors of direct interest to the Navy or the Department of Defense.*

From 1994 to present, the Academy directly mentored over 1300 pre-college students who excelled or are excelling in college preparatory curricula, 838 of them were mentored in this reporting period (1998-2004). It produced 10 and 11 National Merit or National Achievement Scholars in 2000 and 2001, respectively. The Timbuktu Academy has practically closed the *"academic achievement gaps,"* as per American College Test (ACT) or Scholastic Achievement Test (SAT) scores, between its African American scholars and any other group of students in America, including White and Asian Americans.

Reaching over 5000 students, parents, teachers, counselors, and others per year is another accomplishment of the Timbuktu Academy. The Academy's comprehensive dissemination activities, including its ***60 and 177 presentations*** in 1993-98 and 1999-2005, respectively, contributed to this outreach. The rate of presentations has doubled in this reporting period (1998-2005). We should add that the above 177 also include 26 that were mostly supported by the new grant (No. N00014-4-1-0587).

Our true integration of research and education is signified in part by our twenty-nine (29) physics and twenty-nine (29) teaching, mentoring, and learning (TML) publications in this reporting period.

The Academy's creation of new knowledge (58 publications) and its dissemination activities (177 presentations) partly explain its national model status, *a model that has been institutionalized at SUBR and replicated at 10 colleges and* *universities* throughout Louisiana, and in other states. The broader impact of the Academy is partly sustained by the wider and lasting impact of these publications that go far beyond anecdotes.

Impact on the Enrollment/Graduation in Physics-The impact of SEM-Timbuktu Academy is best illustrated by the growth of the enrollment in physics. Before the Timbuktu Academy's establishment, in 1990-91, the Physics enrollment was 23. With NSF support for the first scholars, this enrollment went to 38 in 1992 and 45 in 1992-93. Upon the funding of SEM-Timbuktu Academy by ONR, this enrollment grew to 55 in 1993-94 and to over 65 in 1994-95 and beyond. As a result of the phase down which started in 2001, no new scholars have been recruited by this project. The Academy, however, just started recruiting new scholars to be supported by the new award.

A dramatic increase in the quality of students and the overall enhancement of the academic and research atmosphere are two key additional gains from SEM-Timbuktu Academy. Even the pre-college scholars of the Academy, from participants in GeSTA to those of the high school programs, demonstrate this quality trait of the Timbuktu Academy. The visible internalization of the locus of control, partly through grasping the law of human performance and its implacable consequences, the acquisition and enhancement of study skills and self-discipline, and the blossoming of positive ambitions fueled in part by results explain the noted increase in quality or competitiveness of the scholars of the Academy as compared to their peers. The Academy understands (see publications and presentations) that the "unwritten curriculum," mostly in the affective domain, partly drives human actions. Learning begets and enables more learning.

Impact on Student Retention Rate- The Office of Planning, Assessment, and Institutional Research has conducted a disaggregated retention study of all departments at Southern University and A&M College. This study included 52 departments and it followed 1994 incoming students and calculated the percentage of retention as of 1997-98. *Of the 52 departments of SUBR, including non-SEM units, the retention rate in Physics was the highest in all cases where two (2) or more 1994 incoming students were considered.* **The retention rate in Physics was 83.33% (including Academy scholars and other physics students).** *The University's average retention rate was 51.55 for the 1994-1998 time periods.* **Unquestionably, the Academy shares the bulk of the credit for this retention rate.** Other units with significant numbers of Academy Scholars (i.e., 5 or more) include Chemistry (15 Scholars) and Mechanical Engineering, in addition to Physics. The retention rates of these units were respectively 67.74% and 55.21%. Both the academic quality of the scholars, at the time of their enrollment, and the systemic mentoring by the Academy contributed to this performance.

Institutionalization and Statewide Replication of the Timbuktu Academy: As per the report from the National Science Foundation's reviewers, the funding of the Louis Stokes Louisiana Alliance for Minority Participation (LS-LAMP) in January 1996 was strongly based on the successful and holistic mentoring model of the Timbuktu Academy. The reviewers made explicit references to the Academy as a basis of their decision to recommend LAMP for NSF funding at the level of $1,000,000 per year for five years. *So, in a direct fashion, the funding of the Timbuktu Academy by the Department of the*

Navy, Office of Naval Research (ONR) helped to build not only the educational infrastructure in physics, chemistry, and engineering at SUBR, but also to do so in most science, engineering, and mathematics departments in some eleven (11) public and private institutions in the State of Louisiana! The extensive experiences gained by Bagayoko and his colleagues in the implementation of the Academy are being transferred to other SUBR departments and to SEM departments in other Louisiana institutions. SUBR, as the statewide lead institution for LS-LAMP, *institutionalized systemic mentoring (à la Timbuktu Academy) in all its Science, Engineering, and Mathematics Departments in January 1997.* With its own funds, it has been providing for $1/4^{th}$ release time for a faculty member, in each of some 11 STEM units, to serve as the Departmental Mentoring Coordinator. The long-term benefits of the implementation of LS-LAMP, we firmly believe, will greatly benefit the nation and they clearly are, at least in part, collateral benefits of the support of the Department of the Navy, Office of Naval Research (ONR) for the Timbuktu Academy. The Timbuktu Academy is the model adopted by LS-LAMP and still continues to provide extensive services to LS-LAMP departments and units for replication. A visit to the web site of the Academy (**http://www.phys.subr.edu/timbuktu.htm**) helps to corroborate this assertion. *We are delighted to report that NSF and the Louisiana Board of Regents just funded LS-LAMP, Phase III, for $1 Million per year for the next five years (2005-2010).*

CONCLUSIONS: We have literally placed the creation of educational, research, and professional value-added on a rigorous scientific basis with our Ten-Strand Systemic Mentoring model and our refereed publications. As such, the Timbuktu Academy constitutes a *national treasure* as attested to by the US Presidential awards for excellence in 2002, for the Academy, and in 1996, for its director.

MORE ON SIGNIFICANCE:

The significance of the work of the Timbuktu Academy first stems from the creation of new knowledge (refereed publications). It equally comes from the production of high quality degree holders in SEM fields, most of whom pursue graduate (i.e., research) degrees. *For the future, the production of new researchers is as critical as that of any new knowledge. The significance of the work of the Academy is partly underscored by the fact that only 52%-60% of Physics BS degree holders enroll in graduate school, nationwide, as per data of the American Institute of Physics (AIP). The graduate school enrollment and success rate of the Physics alumni of the Academy is 70%. Similarly, the 73% and 39% graduate school attendance rates of the Academy's Chemistry and Engineering alumni, respectively, are far above the corresponding national averages. Before the Academy, only 10% of Engineering graduates attended graduate school, according to former Dean Dr. Trent Montgomery.*

We cannot overemphasize the long-term impact of the Academy's enrichment and outreach activities for the pre-college communities. In particular, the more than 1300 directly mentored in our summer programs not only went (or will go) on to college, but also mostly enroll and succeed in SEM disciplines (due to earlier exposure and adequate preparation).

The institutionalization and replication, enabled by our web site, publications, and extensive presentations also portend enormous benefits for this country and for the

Department of Defense. Indeed, the perceived difficulties of the pre-college community in appreciating and engaging in SEM disciplines and careers can only be overcome with sustained efforts from many quarters. *The 10-Strand Systemic Mentoring model of the Timbuktu Academy has already made great contributions to the above ends*.

Another significance of the research work of the Academy, one that deserves some attention on the part of some leaders of the Defense enterprise includes the following: **(1)** Our articles on electronic, structural, optical, and other properties of semiconductors and carbon nanotubes (Please see the attached list of publications) have profound implications, even for the study of nuclei. These papers resolved a problem dating back to the inception of quantum mechanical calculations. Namely, we solved the woeful, theoretical underestimation of the band gaps of semiconductors and insulators as compared to measured values. **The resolution of this problem has some stupendous implications for the design and fabrication of semiconductor-based devices.** A collateral benefit stems from the fact that the method of solution also applies to the prediction of nuclear energy levels in the shell model, opening the way to the theoretical exploration of possibility for a population inversion and the actual construction of a *"gamma ray amplification by stimulated emission of radiation (graser)" device. No mention is needed for non-commercial applications of a "graser."* **(2)** Our many (29 in this period) publications in Education literally placed mentoring and the creation of educational value-added on a scientific basis. **(3)** Our publication in the winter 2000 issue of College Teaching **(Vol. 48, No. 1, pp. 24-27, 2000)** introduces *"A Problem Solving Paradigm,"* also known as problem-solving pentagon because of the five sides of the diagram, that literally places the teaching and learning of problem-solving within the reach of anyone. Incidentally, the types of problems this paradigm prepares someone to solve are not limited to academic or research problems, but also include social, industrial, and military ones. While the 2001 National Research Council (NRC) publication entitled *"Adding it Up: Helping Children Learn Mathematics"* did not cite our work (presumably due to lack of knowledge of it), four (4) of its five (5) strands are identical to four (4) of the five (5) strands of our problem-solving paradigm.

PATENT INFORMATION: Not Applicable

AWARD INFORMATION (from 1998 to 2003)

- **2002 US Presidential Award for Excellence in Science, Mathematics, and Engineering Mentoring** to the Timbuktu Academy (Award Ceremony held at the White House on March 18, 2003).
- **Commendation** of a Panel of Experts of consulted by the Louisiana Board of Regents for the quality of the Graduate component of the Timbuktu Academy (2002).
- **Louisiana Board of Regents' Award** to the Director of the Academy for services in the Speaking of Science program. January 2003.
- 43, 47, 39, 52, 52, 45, and 15 **Summer Research Awards** to scholars of the Timbuktu Academy in 1998, 1999, 2000, 2001, 2002, 2003, and 2004, respectively. The average funding level of these awards is $5,000 per student and per summer. The decrease in 2003-2004 is the result of the phase-down.

- **Graduate Fellowships** and Assistantships earned by alumni of the Timbuktu Academy to pursue advanced degrees in universities across the country, including Cornell, Georgetown, Georgia Tech, Purdue, University of Florida (Gainesville), Louisiana State University, Southern University, University of Kentucky, University of Iowa, California Institute of Technology, etc.
- **Award of Volunteers in Public Schools** to the Director of the Academy for the long-standing support of the Academy and of its personnel to public education.
- **Distinguished Service Awards** to the Director of the Academy for outstanding contributions, Forest Heights Elementary (August 2002).
- **First Place, National Science Bowl Competition** of the National Organization for the Professional Advancement of Black Chemists and Chemical Engineers (NOBCChE), in 2003 and 2004, for the High school senior team of the Timbuktu Academy. In 2005, the Academy's Junior teams place 1St and 2nd while the senior teams placed 2nd and 3rd. Academy scholars won first place at several local science and quiz bowls from 1998 to 2005.

Particularly noteworthy, from the 1993-98 report, may be the 1996 US Presidential Award for Excellence in Science Mathematics and Engineering Mentoring to the director of the Academy and the National, Exemplary, Undergraduate Program Award to the Academy, from Quality Education for Minorities (QEM) Network in 1996. The 1994 Commendation for the undergraduate physics program at SUBR, by the Louisiana Board of Regents, is another significant distinction.

PUBLICATIONS

Please see the publications lists submitted in 1998 for the previous **twenty-two (22) Physics and twelve (12) TML publications** made in Phase I (1993-98) of the project (Award No. N00014-93-1-1368).

Please also see the web sites of the Academy Director, Dr. Bagayoko, for a detailed listing of the one **hundred sixty seven (167) presentations** made from 1993 to 2002, one hundred seven (107) of which were made in Phase II, from 1999 to 2003 (http://www.phys.subr.edu/faculty/bagayoko).

THE TIMBUKTU ACADEMY IN THE PRESS

Also attached to this final report are illustrative excerpts from the press on the Timbuktu Academy. In particular, a spring 2005 feature article in the Black Collegian (http://www.blackcollegian.com/issues/2ndsem05/timbuktu2005-2nd.shtml) and one in the Science Next Wave of the American Association for the Advancement of Science (AAAS) are included.

<u>PART I</u>: MOSTLY REFEREED AND MOSTLY PHYSICS PUBLICATIONS
(29 Physics Articles and 5 Teaching, Mentoring and Learning (TML) Articles)

34. *"Structural, Elastic, and Electronic Properties of Deformed Carbon Nanotubes under Uniaxial Strain." A. Pullen,* G. L. Zhao, D. Bagayoko, and L. Yang. Accepted for Publication in Physical Review B (2005). (Mr. Pullen is a former Scholar currently pursuing a Ph.D. in Physics at Caltech.)

33. *"Re-examination of the Ab-initio Calculation of the Electronic Structures of ZnSe, Ge, and GaAs."* G. L. Zhao, L. Franklin, and D. Bagayoko. Submitted to Physical Review B in July 2004.

32. *"LDA and LCAO-BZW Description of Electronic Properties of Wurtzite Zinc Oxide (w-ZnO)."* Diola Bagayoko, Lashounda Franklin, and G. L. Zhao, submitted to 2005 Proceedings of NSBP Annual Conference in Orlando, FL, USA.

31. *"Predictions of Electronic, Structural, and Elastic Properties of Cubic InN."* Diola Bagayoko, Lashounda Franklin, and G. L. Zhao, accepted for publication, Journal of Applied Physics, Vol. 96, No. 8, 15 October 2004.

30. *"Density Functional Band Gap of Wurtzite InN."* Diola Bagayoko and Lashounda Franklin, Accepted for Publication in the Journal of Applied Physics (June 2005).

29. *"Effective Masses of Charge Carriers in Selected Symmorphic and Nonsymmorphic Carbon Nanotubes."* G. L. Zhao, D. Bagayoko, and L. Yang, Phys. Rev. B 69, 245416, June 2004.

28. *"BZW Results for the Band Gaps of Nanoscale, Bulk, and Novel Semiconductors."* Diola Bagayoko, G. L. Zhao, Saleem Hasan, Troy D. William*, Yixin Luo*, Lashounda Torrence*, and Monika Wright**. Former undergraduate (**) and graduate (*) students of Bagayoko and Zhao. Proceedings, Malian Symposium of Applied Sciences (MSAS), Bamako, Mali. ISBN No. 951-42-7322-2, Pages 32-36, University of Oulu Press, Oulu, Finland, 2002.

27. *"GLOBE: An Ideal Platform for Science Education and Global Climate Change Research (GCCR)."* D. Bagayoko, R. L. Ford, and R. Boger. Accepted for Publication in the 2002 Proceedings of the Malian Symposium of Applied Sciences (MSAS), Bamako, Mali. ISBN No. 951-42-7322-2, Pages 145-150. University of Oulu Press, Oulou, Finland, 2002.

26. *"Electronic Structure of Short Carbon Nanobells."* G. L. Zhao, D. Bagayoko, and E. G. Wang, Modern Physics Letters B., Vol. 17, 375 (2003).

25. *"The BZW Method and the Electronic Properties of Zinc Selenide (ZnSe)."* Lashounda Torrence, Diola Bagayoko, and G. L. Zhao. Accepted for publication in Proceedings, 2002 Annual Conference of the Louisiana Academy of Science, Baton Rouge, Louisiana.

24. *"The Metallic Nature of Boron Layers in Magnesium Diboride (MgB_2)."* G. L. Zhao, A. Pullen, and D. Bagayoko. International Journal of Modern Physics B, Vol. 17, Nos. 30 & 31, Pages 5905-5910, 2004.

23. *"A Mathematical Solution of the Band Gap Problem."* D. Bagayoko, G. L. Zhao, and S. Hasan. In Contemporary Problems In Mathematical Physics, Edited by Jan Govaerts, M. Norbert Hounkonnou, and Alfred Z. Msezane, World Scientific, London (ISBN 981-02-4935-7). Pages 222-

232 (2002).

22. *"Basic and Research Training for the New Millennium: the Model of the Timbuktu Academy."* D. Bagayoko, R. Bobba, E. L. Kelley, and S. Hasan. Journal of Materials Education, Vol. 24 (1-3), Pages 177-184, 2002.

21. *"Density of States, Charge Transfer, and Optical Properties of Magnesium Diboride."* D. Bagayoko and G. L. Zhao. International Journal of Modern Physics B, Vol. 16, No. 4, 571-581, (2002).

20. *"Ab-Initio Description and Prediction of Properties of Carbon-Based and Other Non-Metallic Materials."* D. Bagayoko, G. L. Zhao, and S. Hasan. Proceedings of the Sixth Applied Diamond Conference/Second Frontier Carbon Technology Conference (ADC/FCT) 2001, Auburn University, August 4-8, 2001. Pages 544-549, 2001. ISBN# 0-9710327-0-X, NASA/CP-2001-210948.

19. *"Superconducting Gap Symmetry from Repulsive Interaction in a Spin Singlet Channel."* Yuri Malozovsky, J. D. Fan, and D. Bagayoko. Physica C 364-365, Pages 59-65, 2001.

18. "*Predicted Electronic Properties of Cubic Silicon Nitride (c-Si_3N_4)*, D. Bagayoko and G. L. Zhao. Physica C 364-365, Pages 261-264, 2001.

17. "*Anomalous Isotope Effect in Narrow Band Superconductors.*" G. L. Zhao and D. Bagayoko. Physica C 364-365, Pages 21-23, 2001.

16. *"The BZW Method and Calculations of Electronic and Related Properties of Zinc Oxide (ZnO)."* D. Bagayoko and G. L. Zhao.

15. *"Temperature Dependence of the Anisotropic Gap in $Yba_2Cu_3O_7$." G. L. Zhao and D. Bagayoko, Physica C 341-348,161-162, 2000.*

14. *"Electronic Structure and Fermi Surface of CrO_2."* N. E. Brener, J. M. Tyler, J. Callaway, D. Bagayoko, and G. L. Zhao, Physical Review B61, No. 24, 16582-16588, 2000.

13. "*Le Montage ou développement de Projets Sponsorisés." D. Bagayoko and M. Diarra,* Refereed Proceedings, First Mali Symposium on Applied Sciences. University of Mali, Bamako, Mali, West Africa.. Pages 185-192. Editor: Dr. Seydou Fad; Publisher: Oulu University Press, 2001. ISBN: 951-42-6403-7.

12. *Description et Prédiction des Propriétées Electroniques des Matériaux."* D. Bagayoko, Refereed Proceedings, First Mali Symposium on Applied Sciences (MSAS). University of Mali, Bamako, Mali, West Africa.. Pages 185-192. Editor: Dr. Seydou Fad; Publisher: Oulu University Press, Oulu, Finland, 2001. ISBN: 951-42-6403-7.

11. *"Basic and Advanced Trigonometry for All."* D. Bagayoko, 2002. A reform-imbued user manual.

10. *"Polaronic Effect in Materials with Ferroelectric Phase Transitions."* Y. M. Malozovsky, J.D. Fan, D. Bagayoko and J. T. Wang International Journal of Modern Physics B, Nos. 29, 30 & 31, pp. 3555- 3559, 1999.

9. *"How Can An Atom Or Ion Remember Its Initial State?"* J. T. Wang, F. Tang, and D. Bagayoko,

International Journal of Modern Physics B, Vol. 13, Nos. 29, 30, 31, pp. 3830-3834, 1999.

8. *"Predictive Ab-Initio Computations of Properties of Ferroelectric Materials."* D. Bagayoko and G. L. Zhao, International Journal of Modern Physics B Vol.13 Nos. 29, 30 & 31, pp 3767-3773, 1999.

7. *"Ab-Initio Calculations of Superconducting Properties of $YBa_2Cu_3O_7$."* G. L. Zhao and D. Bagayoko, International Journal of Modern Physics B Vol. Nos.29, 30 & 31 pp. 3579-3581, 1999.

6. *"A Problem Solving Paradigm."* D. Bagayoko, Saleem Hasan, and Ella L. Kelley. College Teaching, Vol. 48, No. 1, pp. 24-27, 2000.

5. *"Ab-initio Calculations for the Superconducting Properties of Yba2Cu3O7",* G. L. Zhao and D. Bagayoko. The International Journal of Modern Physics B Vol.13, Nos. 29-31, pages 3579-3581 (1999).

4. *"Misconceptions and the Certainty of Response Index (CRI)."* Saleem Hasan, D. Bagayoko, and Ella L. Kelley. Physics Education (UK) 34 (5), pp. 294-299, 1999.

3. *"Electronic Structure and Charge Transfer in 3C- and 4H-SiC."* G. L. Zhao and D. Bagayoko. New Journal of Physics (NJP), 2000, UK; http://www.iop.org/EJ/abstract/1367-2630/2/1/316

2. *"Predictive Calculations of Properties of Molecules, Clusters, and Semiconductors."* D. Bagayoko, G. L. Zhao, and Troy D. Williams. Proceedings, 1999 Meeting of the National Society of Black Physicists (NSBP '99), Atlanta, Georgia, March 21 (1999).

1. *"Local-Density-Functional Prediction of Electronic Properties of GaN, Si, C, and RuO_2"* G. L. Zhao, D. Bagayoko, and T. D. Williams. Physical Review B60, 1563, 1999.

<u>PART II</u>: TEACHING, MENTORNG, AND LEARNING (TML) PUBLICATGIONS (Scholarly work on mentoring, teaching and learning, educational research; for, what is not recorded is likely to be lost and likely not to be replicated)

25. *"Two Significant Others for Effective Professional Development."* By D. Bagayoko, Luria Stubblefield, Janet Reed, Ella L. Kelley, and Saleem Hasan. Journal of Urban Education (ISSN: 1546-3206), Vol. 2, Issue 1, Pages 42-56, 2005.

24. *"Mapping The Concept of Change."* D. Bagayoko, S. Hasan, and T. Reese. Accepted for publication in the Proceedings of the International Conference on College Teaching and Learning. Board Resort, Disneyland, Orlando, Florida, January 4, 2005.

23. *"Mapping Basic Mechanics Concepts."* D. Bagayoko and S. Hasan. Accepted for publication in the Proceeding of the International Conference on College Teaching and Learning. Board Resort, Disneyland, Orlando, Florida, January 3, 2005. .

22. *"Homage to a True Leader: R. L. Ford, Competence, Dedication, and Courage for Emulation."* D. Bagayoko, Proceedings, LS-LAMP Conference (ISSN 1554-7604), Page 248-249, 2004.

21. *"Correlations Between the Global Learning and Observations to Benefit the Environment (GLOBE)*

and the Louisiana Mathematics Content Standards." Diola Bagayoko and Deborah Mohammad. A 47 page manual for integrating GLOBE into the teaching and learning of mathematics. ISBN No. 0-9715233-2-0. Publisher: LS-LAMP, Baton Rouge, Louisiana, December 2003.

20. *"Preparing for Global Competitiveness: Utilizing Internet Tools in Research, Learning, and Teaching."* D. Bagayoko. Proceedings, LS-LAMP National Student Research Conference, Sheraton Hotel, New Orleans, Louisiana, November 21-23, 2003.

19. *"Mentoring for Global Competitiveness."* D. Bagayoko and Luria Stubblefield, Proceedings, LS-LAMP National Student Research Conference, Sheraton Hotel, New Orleans, Louisiana, November 21-23, 2003.

18. *"Making, Closing, and Avoiding Academic Achievement Gaps."* D. Bagayoko. Accepted for Publication in Louisiana Weekly, New Orleans, Louisiana.

17. *"Closing Academic Achievement Gaps."* D. Bagayoko. Challenge, Vol. 13, No. 1, Fall 2002.

16. *"Connecting Teaching and Mentoring: My Contributions to the American Academy."* D. Bagayoko. Book Chapter in African Perspectives in American Higher Education, Edited by Festus Obiakor and Jacob U. Gordon, Nova Science Publishers, Inc., 2002.

15. *"The Philosophical Foundations of Systemic Mentoring at the Timbuktu Academy."* D. Bagayoko. Science Next Wave, American Association for the Advancement of Science (AAAS). An online publication available at http://nextwave.sciencemag.org/, 2002.

14. *"Integrating Research and Education through Mentoring."* D. Bagayoko. Ernergia, Vol. 13, No. 4, Pages 5-6, 2002.

13. *"GLOBE"(Global Learning and Observations to Benefit the Environment)*. Proceedings, Second Malian Symposium of Applied Sciences (MSAS). Rebecca Boger and D. Bagayoko, ISBN No. 951-42-7322-2, Pages 151-161. University of Oulu Press, Oulou, Finland, 2002.

12. *"The Arts and Science of Mentoring at the Timbuktu Academy."* D. Bagayoko. Proceedings, 2002 Conference of the National Organization for the Professional Advancement of Black Chemists and Chemical Engineers (NOBCChE), New Orleans, Louisiana.

11. *"Higher Education in Mali: A Provocative Overview."* by D. Bagayoko and Moussa M. Diawara. A chapter in "African Higher Education: an International Reference Handbook." Edited by Damtew Teferra and Philip G. Altbach (2002). Eds. Bloomington, Indiana: Indiana University Press.

10. *"Meta-Correlations Between GLOBE and Science and Mathematics Education Reforms."* D. Bagayoko and R. L. Ford. Published in (in the US and Elsewhere). In the Correlations… (ISBN No. 0-9704609-8-8, Pages 5-7, March 2001.

9. *"Reverse Digital Divide: A Case Study at the Timbuktu Academy and a Model for the Future."* D. Bagayoko. Proceedings, Tennessee State University (TSU)-AOL Time Warner HBCU Digital Divide Conference held at Jackson State University (JSU). (http://digitaldivide.jsums.edu/bagayoko/PaperDigitallDivideTSUFinal100101.doc)

8. *"Correlations Between the Global Learning and Observations to Benefit the Environment (GLOBE) and the Louisiana Science Content Standards."* D. Bagayoko and Deborah Muhammad. A 37 page

book published by the Timbuktu Academy. Printed in Baton Rouge, Louisiana, USA. ISBN# 0-9704609-8-8. (http://docushare.subr.edu/sudocs/dscgi/ds.py/GetRepr/File-446/html)

7. *"The Law of Performance and the Excellence in Research."* D. Bagayoko. Proceedings of the 15th Annual High Technology Student Expo of the National Association for Equal Opportunity (NAFEO) in Higher Education, ISBN 0-9704609-3-7, Pages 27-32, 2001.

6. October 18, 2000. Recording of a 30 Minute Video Tape on *"A Rosetta Stone for Competitive Education."* This media publication (Video Tape), has been shown in the fall of 2000 for a full month, several times per week, so as to reach 99% of Louisiana households. Estimated audience in tens of thousands.

5. August 9, 2000. One hour video recording on *"The Genesis of Genius."* This media publication (video tape) has been shown in the fall of 2000 for a full month, several times per week, so as to reach 99% of Louisiana households. Estimated audience in tens of thousands.

4. *"Expanding GLOBE Participation: An Emerging Model for Diversification."* Robert L. Ford and Diola Bagayoko, International Conference of the Global Learning and Observations to Benefit the Environment (GLOBE), Annapolis, Maryland, July 19, 2000.

3. *"Avoiding or Closing the Academic Achievement Gap."* D. Bagayoko, S. Hasan, and R. L. Ford, Department of Energy and Louis Stokes Louisiana Alliance for Minority Participation (LS-LAMP) Annual Conference, February 12, 2001, Radisson Hotel, New Orleans, Louisiana. ISBN No. 0-970460-4-5, Page 54-56 (2001).

2. *"Fundamentals of Mentoring and Networking."* D. Bagayoko, Robert L. Ford, and Ella L. Kelley; a chapter in a monograph entitled "Scholarly Guideposts for Junior Faculty Members." Published by Quality Education for Minority (QEM) Network. Washington, D.C., February, 2000.

1. *"Accountability in Teaching and Learning: The Covenant."* D. Bagayoko et al. A publication of the Faculty Senate at Southern University and A&M College, Baton Rouge, Louisiana. Available on the web (http://www.phys.subr.edu/senate).

LIST OF PRESENTATIONS (1999 to 2005)

Science, Engieering and Mathematics at the Timbuktu Academy
Grant No. N00014-98-1-0748
Southern University and A&M College

177. February 26, 2005. Marriott Washington Hotel, Washington, D.C. 2005 National Conference of Quality Education for Minorities (QEM) Network. *"An Ultimate Part of Solutions to Disparities: A Competitive Education and the Related 'Ways and Means'."* D. Bagayoko. Audience: 35 University officials and faculty members.

176. March 25, 2005. Los Angeles, CA. March Meeting of the American Physical Society (APS). *"Structural, Elastic, and Electronic Properties of Deformed Carbon Nanotubes under Uniaxial Strain." A. Pullen SUBR & (Caltech),* G. L. Zhao, D. Bagayoko, and L. Yang (NASA), Bull. APS, Vol. 50, No. 1, Page 1420 (2005).

175. March 23, 2005. Los Angeles, CA. March Meeting of the American Physical Society (APS). *"Re-examination of Ab-initio Calculation of the Electronic Structure of Zn Se, Ge, and GaAs."* G. L. Zhao, L. Franklin, and D. Bagayoko, Bull. APS, Vol. 50, No. 1, Page 1073 (2005).

174. March 22, 2005. Los Angeles, CA. March Meeting of the American Physical Society (APS). *"True LDA Band Gaps of Wurtzite and Cubic Indium Nitride (w-InN and c-InN)."* D. Bagayoko, G. L. Zhao, and L. Franklin. Bull. APS, Vol. 50, No. 1, Page 617 (2005).

173. February 18, 2005. Orlando, Florida, Disneyland. 2005 National Conference of the National Society of Black Physicists (NSBP) and of the National Society of Hispanic Physicists (NSHP). *"Local Density Functional Description of Electronic Properties of Wurtzite Zinc Oxide (ZnO)."* D. Bagayoko, G. L. Zhao, and L. Franklin. Audience: 17 faculty members, graduate students, and federal lab researchers.

172. February 17, 2005. Orlando, Florida, Disneyland. 2005 National Conference of the National Society of Black Physicists (NSBP) and of the National Society of Hispanic Physicists (NSHP). *"A Competitive Edge for Recruitment: The Versatility and Wonders of Physics."* D. Bagayoko. Audience: 20 faculty members, graduate students, and federal lab researchers.

171. February 12, 2005. Radisson Hotel, New Orleans, LA. *"Empowerment for Academic Excellence: Avoiding or Closing Academic Achievement Gaps."* D. Bagayoko. Audience: 150 faculty members, program officers, students, etc., from HBCU-UP programs across the country.

170. January 4, 2005. International Conference on College Teaching and Learning. Board Resort, Disneyland, Orlando, Florida. *"Mapping The Concept of Change."* D. Bagayoko, S. Hasan, and T. Reese. Audience: 40 faculty members and researchers from around the world.

169. January 3, 2005. International Conference on College Teaching and Learning. Board Resort, Disneyland, Orlando, Florida. *"Mapping Basic Mechanics Concepts."* D. Bagayoko and S. Hasan. Audience: 33 faculty members and researchers from around the world.

168. December 7, 2004. Henton Room, Student Union, SUBR: *The Research and Experience Base of the Timbuktu Institute, Inc.* A presentation to 7-10 officials (BESE, Local School Board, Legislature, and Community).

167. December 1, 2004. Tensas Parish Schools (Davidson, Newellton, and Academy). Three (3) Presentations on *"The Value of Education and Careers in Science and Technology."* D. Bagayoko. Audience: Davidson High: 127 students and (49 males, 78 females; 126 Blacks, 1 White) and 14 teachers; Newellton High: 83 Students (30 males, 53 females; 82 Blacks , 1 White) and 14 teachers (3 males, 11 females; 2 Blacks, 12 Whites); St. Joseph Academy: 50 Students (1 Black, 49 Whites; 17 males, 33 females) and 5 teachers.

166. November 19, 2004. Green T. Lindon Elementary School, Youngsville, Louisiana. Three Presentations: *"The Hands-on Scientific Method for 2nd Grade Students."* D. Bagayoko. Audience: Three classes of eighteen (18) students for a total of fifty four (54) students [6 Blacks, 48 Whites; 29 males, 25 females].

165. November 17, 2004. J. K. Haynes Elementary Charter School, Baton Rouge, Louisiana. Presentation: *"Academic Excellence by Design."* D. Bagayoko. Audience: Twenty seven (27) elementary school teachers and staff [3] of J. K. Haynes Elementary Charter School and of Children's Charter School [4 males, 23 females; 4 Whites, 23 Blacks].

164. November 2, 2004. Vermilion School System, Vermilion Parish, Louisiana. Two Hour Presentation: *"Teaching Effective Problem-Solving."* Audience: 29 Teachers (8 males, 21 females; 1 Black, 28 White; 15 elementary, 10 middle, and 4 high school teachers).

163. October 28, 2004. Central Private School, Baker, Louisiana. Presentation: *"Careers in Science and Technology and the English and Mathematics It Takes."* D. Bagayoko. Audience: Fifty (50) middle school students (8th grade) and four (4) teachers.

162. October 22, 2004. Magnolia Room, Mayberry Cafeteria, Southern University and A&M, Baton Rouge (SUBR), Louisiana. Presentation: *"Faculty Expectations and Roles."* D. Bagayoko. Audience: Fifty (50) – including officials of SU System and campuses and new faculty members from all five campuses.

161. October 19, 2004. Capital City Rotary Club, Baton Rouge, Louisiana. Presentation: *"The Timbuktu Academy's Paradigm of Education: The Reason It Received The 2002 US Presidential Award For Excellence."* D. Bagayoko. Audience: Ten (10) members of the Capital City Rotary Club.

160. October 8, 2004. Hotel Meridien President, Dakar, Senegal. First Conference of Intellectual from Africa and the Diaspora (CIAD). Presentation: *"A Comprehensive Approach to the Science Education, Research, and Development."* D. Bagayoko. Audience: Fifty (50) scientists and policy makers from Africa and the Diaspora.

159. October 1, 2004. Evangeline Elementary School, Evangeline, Louisiana. Presentation: *"Careers in Science and Technology and the English and Mathematics It Takes."* D. Bagayoko. Audience: Sixty (60) 6th through 8th grade students.

158. September 13, 2004. Clay Young's Morning Show, On Wooddale Boulevard, Baton Rouge. Thirty Minute Interview: *"Closing Academic Achievement Gaps."* D. Bagayoko. Audience: in Thousands (in Baton Rouge and surrounding parishes).

157. September 11, 2004. Press Box, A. W. Mumford Stadium, SUBR. Radio Interview: *"The Timbuktu Academy: Its Programs That Cultivate Academic Excellence (and close achievement gaps)."*
D. Bagayoko. Audience: in Thousands (pre-game show the SU Sport Network).

156. September 8, 2004. Catahoula Parish, Louisiana. Presentations: *"Careers in Science and Technology and the English and Mathematics It Takes."* D. Bagayoko. Audience: Three (3) presentations at three (3) different schools at audiences of eighty-seven (87), ninety (90), and two hundred eighteen (218) high school students respectively.

155. September 7, 2004. Conference Room in the Agricultural Research and Extension Center contiguous to the campus of SUBR, Baton Rouge. Presentation: *"An Overview of the Board of Regents Support Fund Program and The Development of Competitive Proposals."* D. Bagayoko. Audience: Thirty (30) faculty members, including department chairs and two deans (Business and Public Policy).

154. August 7, 2004. University Cheick Anta Diop, Dakar, Senegal. Interview with Radio France Internationale (RFI): *"The Significance of the BZW Method for Materials Research and Development and of the 2004 MSAS Conference."* D. Bagayoko and Ouateni Diallo. Audience: In hundreds of Thousands (RFI is broadcast over the entire continent of Africa and others).

153. August 6, 2004. University Cheick Anta Diop, Dakar, Senegal. Présentation: *"La Loi de la Performance Humane: Applications des Mathématiques au Développement."* D. Bagayoko. Fifty (50) mostly mathematics faculty members and researchers from around the world.

152. August 3, 2004. Solar Energy Research Center (CRES in French), University of Bamako, Mali. Presentation: *"Predictive Calculations of Electronic Properties of Atoms, Molecules, and Semiconductors."* D. Bagayoko. Audience: One hundred twenty (90) science, mathematics, and engineering researchers and university faculty from 14 countries around the world.

151. August 2, 2004. Solar Energy Research Center (CRES in French), University of Bamako, Mali. Presentation: *"Education, Recherche, et le Développement Compétitif."* D. Bagayoko. Audience: One hundred twenty (120) science, mathematics, and engineering researchers and University faculty from 14 countries around the world.

150. July 22, 2004. Chase Suites, Corporate Boulevard, Baton Rouge, Louisiana. Presentation (at 6:00 PM): *"The Scientific Method for All."* D. Bagayoko. Audience: Twenty four (24) 7th through 12 grade students.

149. July 22, 2004. School of Nursing, Southern University and A&M College, Baton Rouge (SUBR), Louisiana (at 3:00 PM). Presentation: *"Two Significant Others for Effective Professional Development."* By D. Bagayoko, Luria Stubblefield, Ella L. Kelley, and Saleem Hasan. Audience: Ten (10) Conferees, mostly faculty members and teachers.

148. July 21, 2004. High Technology Classroom, School of Engineering, SUBR, Louisiana. Presentation: *"The Timbuktu Academy: Paradigm, Programs, Activities, and Results."* D. Bagayoko. Audience: Fifty (50) officials from The US Navy and SUBR, including Admiral Ann Rondeau and several officers of the Navy, Chancellor Edward Jackson, the vice chancellors, deans, department chairs, and key faculty and staff members.

147. July 12, 2004. First Floor, Higgins Hall, Southern University and A&M College, Baton Rouge (SUBR). Presentation: *"Internship Experiences and the Law of Human Performance."* D. Bagayoko. Audience: Fifteen (15) McNair Scholars at SUBR.

146. July 7, 2004. National Science Foundation, Arlington, VA. Presentation: *"The Louis Stokes Louisiana Alliance for Minority Participation (LS-LAMP): Logical framework, operation, and results."*

D. Bagayoko. Audience: three (3) members of a national review panel, three (3) NSF program officers, and three (3) representative from Louisiana.

145. May 29, 2004. New Jersey Institute of Technology, Newark, New Jersey. Presentation: *"The Creation of Educational Value Added: From Pre-K to College and Beyond."* D. Bagayoko. Audience: 31 attendees, mostly professionals and university faculty members.

144. May 28, 2004. Rutgers University, Rutgers, New Jersey. National Science Foundation (NSF) funded **16th International Workshop on New Developments in Condensed Matter Theory**. Poster Presentation: *"A Mathematical Solution of the Band Gap Catastrophe."* D. Bagayoko. Audience: Over 100 condensed matter theorists, including over 40 graduate students.

143. April 29, 2004. Springfield High School, Springfield, Louisiana, 8 AM to 12 Noon. *"Education, Job Tasks, and Rewards for Your Career in Science."* D. Bagayoko. Audience: 93 students in 4 different classes and 8 teachers.

142. April 23, 2004. Albany Middle School, Albany, Louisiana. *"Careers in Science, Mathematics, and Engineering, and the English and Mathematics It Takes."* D. Bagayoko. Audience: 65 Middle School Students in 3 different classes and 6 teachers.

141. April 21, 2004. Brighter Horizon School, Wooddale Boulevard, Baton Rouge, Louisiana. *"Careers in Science, Mathematics, and Engineering, and the English and Mathematics It Takes."* D. Bagayoko. 25 African American High School Students (mostly females) and 4 teachers.

140. April 13, 2004. Baton Rouge Community College's Science Club. "*Careers in Science, Mathematics, and Engineering, and the English and Mathematics It Takes."* D. Bagayoko. Audience: 50 BRCC Students and 5 Staff Members.

139. April 2, 2004. Dillard University, New Orleans, LA. The White House Initiative for HBCU's. *"Winning a Federal Grant."* D. Bagayoko as the representative of the Southern University System. Audience: 52 faculty members from HBCU's around the country.

138. March 6, 2004. Baton Rouge Sigma Foundation. *"Careers in Science, Mathematics, and Engineering, and the English and Mathematics It Takes."* D. Bagayoko. Audience: 30 African-American girls and 4 staff members.

137. March 4, 2004. St. Charles Elementary, New Orleans, LA. "*The Scientific Method for all."* D. Bagayoko. Audience: 133 students (72 males, 61 females); 112 white and 21 black) and 15 teachers (all female, 1 black).

136. February 24, 2004. Lawrence Berkeley Laboratory, Berkeley, California. *"Ab-initio, Predictive Calculations of Energy Gaps."* D. Bagayoko. Audience: 7 research scientists and 3 undergraduate students from Jackson State University.

135. February 23, 2003. Lawrence Berkeley Laboratory, Berkeley, California: *"Outreach, Diversity, and Systemic Mentoring."* D. Bagayoko. Audience: 37 Researchers, UC Berkeley faculty members, and Laboratory staff.

134. February 21, 2004. Omni Shoreham Hotel, Washington, DC. Joint National Conference of the National Society of Black Physicists and Black Physics Students and of the National Society of Hispanic

Physicists. *"Closing and Avoiding Achievement Gaps: From Pre-K to Graduate School and Beyond."* D. Bagayoko. Audience: 35 scientists, educators, policy makers, and graduate students.

133. February 5, 2004. Cut Off Elementary, Cut Off, Louisiana, 1:30 PM to 2:20 PM. *"The Scientific Method for All."* D. Bagayoko and Monika Wright. Audience: 80 elementary school students and 7 Teachers.

132. February 3, 2004. Community School for Apprenticeship Learning (CSAL), Baton Rouge, Louisiana. *"Careers in Science, Mathematics, and Engineering, and the English and Mathematics It Takes."* D. Bagayoko. Audience: 19 middle and high school students, and 3 teachers.

131. January 21, 2004. St. Rita Elementary School, Harahan, Louisiana. 3 PM- 4 PM. *"Educational Reform and the Ten Strands of Competitive Education."* D. Bagayoko. Professional development for 17 teachers.

130. January 21, 2004. St. Rita Elementary School, Harahan, Louisiana, 8 AM to 3 PM. *"Careers in Science, Mathematics, and Engineering, and the English and Mathematics It Takes."* D. Bagayoko. Audience: 4 different classes of 20-25 students (for a total over 90 students and 3 teachers).

129. January 9, 2004. St. Angela Merici School, Metairie, Louisiana. *"Careers in Science, Mathematics, and Engineering, and the English and Mathematics It Takes."* D. Bagayoko. Audience: 20 eighth grade students and 2 teachers.

128. January 8, 2004. Egan Elementary, Egan, Louisiana. *"The Scientific Method for All."* D. Bagayoko. Audience: 22 elementary school students and 3 teachers.

127. November 22, 2003. Sheraton Hotel, New Orleans, Louisiana. "Mentoring for Global Competitiveness." *D. Bagayoko and Luria Stubblefield. Audience: 28 faculty members and a few students.*

126. November 22, 2003. Sheraton Hotel, New Orleans, Louisiana. *"Preparing For Global Competitiveness: Utilizing Internet tools in Research, Learning, and Teaching."* D. Bagayoko. Audience: 117 undergraduate students and 38 faculty members and research scientists.

125. November 21, 2003. Green T. Elementary School, Youngsville, Louisiana. *"The Scientific Method for All."* Audience: different classes for 20-25 students for a total over 80 students and 6 teachers.

124. November 19, 2003. J. K. Haynes Elementary Charter School, Baton Rouge, Louisiana. *"Keys to Competitiveness in Teaching and Learning: The Power Of Relevant Practice In Learning."* D. Bagayoko. Audience: 12 Teachers and 3 School Administrators.

123. Saturday, October 18, 2003. in Bamako, Mali, West Africa. Interview with Jeune Afrique Economie on *"The Power Law of Performance and the Promotion of Intellectual Excellence.*"
Appeared throughout Africa and the rest of the francophone world.

122. October 15, 2003. in Bamako, Mali, West Africa. Interview with Radio France Internationale (RFI) on *"The Diaspora (Intelligentsia) and Development."* Aired throughout Africa on October 16, 2003.

121. August 28, 2003. 9-10 AM, in Yaounde, Cameroon, West Africa. *"Higher Education, Research, and GLOBE."* A presentation to Global Learning and Observations to Benefit the Environment (GLOBE) workshop participants from 9 countries and the US. D. Bagayoko. Audience: 57 participants.

120. August 20, 2003. 10:00 AM- 2:00 PM. *"Grantsmanship, BORSF, and Mentoring for Competitiveness."* A Presentation to new faculty members in the School of Architecture, SUBR. D. Bagayoko.

109. June 18, 2003.-*"A National, Exemplary Educational Program: The Timbuktu Academy."* Department of the Navy, Office of Naval Research (ONR), Arlington, VA. Audience: 30 DoD and ONR official and 7 educational project directors.

108. June 3, 2003. 11:00 AM. Department of Foreign Languages, SUBR. Presentation: *"Culture of Mali."* D. Bagayoko. Audience: 15 African-American students mostly majoring in French.

107. June 2, 2003. Louisiana School of the Deaf on Bright Side lane. Presentation to the LSU LaSIP and LINCS project: *"Scientific Inquiry and Applications in Classroom Teaching."* D. Bagayoko. Audience: 41 elementary and middle school teachers.

106. May 28, 2003. Houston Intercontinental Hotel, Houston, Texas. NACME 2003 Forum. Presentation: *"The Model of the Timbuktu Academy, a 2002 US Presidential Awardee for Excellence in Science, Mathematics, and Engineering Mentoring."* D. Bagayoko. Audience: 22 faculty members and professionals.

105. May 13, 2003. Mire Elementary School (1^{st}-6^{th} grades), Mire, Louisiana (St. Martin Parish). Presentation: *Careers in Science and Engineering, and the English and Mathematics it Takes.* Audience: 120 6^{th}-8^{th} graders.

104. April 1, 2003. St. Charles Elementary School, Thibodeaux, Louisiana. D. Bagayoko assisted by Ms. Paulette Johnson. Presentation: "*The Scientific Method for All."* Audience: 64 2^{nd} and 3^{rd} graders, and five teachers.

103. March 19, 2003. Forest Height Elementary School, Baton Rouge, Louisiana. Professional Development Activity. Presentation: *"The Scientific Basis for High Expectations for All Students."* Audience: 34 teachers and administrators (4).

102. March 15, 2003. Pre-service Workshop, College of Education, Southern University and A&M College in Baton Rouge. Presentation: *"Correlations Between GLOBE and Science and Mathematics Content Standards."* Audience: 30 Education Students (23) and Faculty.

101. March 8, 2003. Airport Hilton, New Orleans, Louisiana. National Science Foundation (NSF)-Funded Careers Workshop for Junior Faculty Member, Quality Education for Minority (QEM) Network. Presentation: *"Integrating Research and Education."* Audience: 75 Junior University faculty members, 5 Professionals (from QEM and NSF)

100. March 5, 2003. Austin, Texas. March Meeting of the American Physical Society (APS). Presentation: *"Calculated Electronic Properties of Zinc Oxide (ZnO)."* D. Bagayoko and G. L. Zhao. Audience: 35 Physics researchers.

99. March 3, 2003. Austin, Texas. March Meeting of the American Physical Society (APS). Presentation: *"Ab-initio Simulation for the Growth Mechanism of CN_x Nanobells." G. L. Zhao, D. Bagayoko, A. Pullen, and E.G. Wang.*

98. February 15, 2003. National Conference of Black Physicists and Black Physics Students, Spelman College, Atlanta, Georgia. Presentation: *"Education and Outreach Activities of the Timbuktu Academy."* Diola Bagayoko and Terrence Reese. Audience: 60 physics faculty members, researchers, and students.

97. February 14, 2003. Chancellor's Mentoring Symposium, Louisiana State University, Baton Rouge, Louisiana. Presentation: *"Mentoring: The Integration of the Cognitive and Affective Domains for Competitiveness."* D. Bagayoko. Audience: 30 university faculty, administrators, and staff.

96. February 6, 2003. Our Lady of Lourdes School, Slidell, Louisiana. Presentation: *"The Versatility and Wonders of Physics."* Audience: 60 students, 1 teacher.

95. February 4, 2003. Dwight D. Eisenhower Elementary School, New Orleans, Louisiana. Presentation: *"The Scientific Method for All."* Audience: 30 students and 1 teacher.

94. January 30, 2003. Clemson University, Greenville, South Carolina. Presentation: *"Addressing the Academic Achievement Gaps Between Minority Students and their Peers."* Audience: 40

93. January 28, 2003. Merrydale Elementary, Baton Rouge, Louisiana. Presentation: *Avoiding or Closing the Academic Achievement Gaps*. Audience: 75 parents and 11 teachers.

92. January 20, 2003. San Diego, California. Fourth International Conference on New Theories, Discoveries, and Applications of Superconductors and Related Material. G. L. Zhao, A. Pullen, and D. Bagayoko. Presentation: *"The Metallic Nature of Boron Layers in Magnesium Diboride."*

91. January 20, 2003. Fayoun and Cairo, Egypt, International Conference on Physics Education. Presentation: *"Implementation of CD-Physics at Southern University and A&M College."*

90. January 3, 2003. Merrydale Elementary, Baton Rouge, Louisiana. Presentation: *"The Secret of Mastery Learning: The Power Law of Practice."* Audience: 34 teachers.

89. December 3, 2002. Haynesville High School, Haynesville, Louisiana. Presentation: *"The Versatility and Wonders of Physics."* Audience: 60 students, 2 teachers.

88. November 22, 2002. Lorenger Elementary School, Lorenger, Louisiana. Presentation: *"The Scientific Method for All."* Audience: 120 students, 9 teachers.

87. November 11, 2002. Albany Middle School, Albany, Louisiana. Presentation: *"The Scientific Method for All."* Audience: 80 students and 6 teachers.

86. October 21, 2002. Louisiana Tech University, Ruston, Louisiana. Louisiana Conference on Commercial Applications of Microsystems, Materials, and Nanotechnologies. G. L. Zhao, L. Torrence-Franklin, and D. Bagayoko. Presentation: *"Electronic Properties of Carbon Nanobells for Field Emission Applications."*

85. October 21, 2002. Department of Science and Mathematics Education (SMED), Southern University and A&M College-Baton Rouge (SUBR), and Louisiana State University (LSU). Presentation: *"The Certainty of Response Index and Misconceptions in Science and Mathematics."* Audience: 30 faculty members and Graduate Students.

84. July 10, 2002. Bamako, Mali, Faculty of Science and Technology, University of Mali at Bamako. Second Malian Symposium for Applied Sciences (MSAS). Robert L. Ford and D. Bagayoko. Presentation (by Bagayoko in French): "GLOBE: An Ideal Platform for Science Education and Global climate Change Research (GCCR)."

83. July 12, 20002. Same location as given above. Presentation: *"The GLOBE Program."* Dr. Rebecca Boger and Dr. Diola Bagayoko (Bagayoko translated, live, from English to French.) Audience: 35 researchers, faculty members, and graduate students.

82. July 8, 2002. Bamako, Mali, Faculty of Science and Technology, University of Mali at Bamako. Second Malian Symposium for Applied Sciences (MSAS). Presentation: *"BZW Results for the Band Gaps of Bulk, Nanoscale, and Novel Semiconductors."* Audience: 75 scientists and university officials.

81. July 3, 2002. Bamako, Mali. International Conference of the Réseau Africain de Mathématiques Appliquées au Développement (RAMAD): Presentation: *"A Mathematical Solution to the Calculated, Unoccupied, Low Energy Catastrophe."* D. Bagayoko. Audience: 130 mathematicians, researchers, and officials of the University of Mali at Bamako.

80. July 1, 2002. Bamako, Mali. International Conference of the Réseau Africain de Mathématiques Appliquées au Développement (RAMAD): Presentation: *"Fitting GLOBE Data for Global Climate Change Research."* D. Bagayoko. Audience: 85 mathematicians and scientists.

79. June 3, 2002. Joint Seminars of The Department of Science and Mathematics Education (SMED), Southern University-Baton Rouge, and Louisiana State University (LSU), Baton Rouge, Louisiana. Presentation: "*Scientific Inquiry.*" Audience: 25 teachers and university faculty.

78. May 17, 2002. Church Point Elementary School, Church Point, Louisiana. Presentation: *Careers in Science, Technology, Engineering, and Mathematics and the English and Mathematics It Takes.* Audience: 78 students

77. May 14, 2002. St. George Catholic Elementary School, Baton Rouge, Louisiana. Presentation: "*Careers in Science, Technology, Engineering, and Mathematics and the English and Mathematics It Takes*." Audience: 167 students

76. May 9, 2002. Breaux Bridge Primary School, Breaux Bridge, Louisiana. Presentation: "*The Scientific Method for All*." Audience: 140 students.

75. May 3, 2002. St. Pius Elementary School, Lafayette, Louisiana. Presentation: *"The Scientific Method for All."* Audience: 140 students.

74. April 25, 2002. Our Lady of Grace Catholic School, Reserve, Louisiana. Presentation: "*Careers in Science, Technology, Engineering, and Mathematics and the English and Mathematics It Takes."* Audience: 120 students.

73. April 23, 2002. Higgins High School, Marrero, Louisiana. Presentation: "*Careers in Science, Technology, Engineering, and Mathematics and the English and Mathematics It Takes."* Audience: 55 students.

72. April 16, 2002. Jones Creek Adventist Academy, Baton Rouge, Louisiana. Presentation: "*Careers in Science, Technology, Engineering, and Mathematics and the English and Mathematics It Takes."* Audience: 27 students.

71. April 9, 2002. Jones Creek Adventist Academy, Baton Rouge, Louisiana. Presentation: "*The Scientific Method for All.*" Audience: 24 students

70. March 27, 2002. Sheraton Hotel, New Orleans, Louisiana. 2002 National Conference of NOBCChE. Presentation: "*Ab-initio Predictive Calculations of Properties of Atoms, Molecules, and Solids.*" By Diola Bagayoko, G. L. Zhao, Troy Williams, LaShounda Torrence-Franklin, Yixin Luo, and Tommy Dodson. Audience: 20.

69. March 26, 2002. North Site Junior High School, Jennings, Louisiana. Presentation: "*Careers In Science Mathematics Engineering and Technology (SMET) and the English and Mathematics it Takes.*" By Diola Bagayoko.

68. March 25, 2002. Sheraton Hotel, New Orleans, Louisiana. 2002 National Conference of NOBCChE. Presentation: "*The Arts and Science of Mentoring at the Timbuktu Academy.*" By Diola Bagayoko and Ella Kelley. Audience: 45.

67. March 22, 2002. Washington, D.C. Twenty-seventh National Annual Conference of NAFEO. Presentation: "*An Innovative and Effective Model for Student Retention in STEM Disciplines: The Timbuktu Academy.*" By Diola Bagayoko. Audience: 30.

66. March 19, 2002. Indianapolis, Indiana. 2002 March Meeting of the American Physical Society (APS). Presentation: "*Ab-initio Calculations of the Electronic Structures of Selected Carbon Nanotubes.*" By Diola Bagayoko and G. L. Zhao. Audience: 100.

65. March 19, 2002. Louisiana State University, Baton Rouge, Louisiana. 2002 Conference of the Louisiana Academy of Sciences. Presentation: "*Correctly Calculated Band Gaps of Semiconductors.*" By Diola Bagayoko, G. L. Zhao, Saleem Hasan.

64. March 14, 2002. Alabama University and A&M College, Huntsville, Alabama. 2002 Joint National Conference of NSBP and NCBPS. Presentation: *The Timbuktu Academy: Systemic Mentoring, Physics Education, and Economic Competitiveness*. By Diola Bagayoko. Audience: 200.

63. January 16, 2002. J. K, Haynes Elementary Charter School, Baton Rouge, Louisiana. An Action Plan for J. K. Haynes Elementary Charter School. Presentation: *Avoiding or Closing Academic Achievement Gaps*. By Diola Bagayoko. Audience: 20 teachers.

62. February 19, 2002. Clemson University, Clemson, South Carolina. Seminar. Presentation: *Avoiding or Closing Academic Achievement Gaps: From Elementary School to College*. By Diola Bagayoko. Audience: 25.

61. February 13, 2002. Jennings High School, Jennings, Louisiana. In-Service Workshop for Jefferson Davis Parish School System. Presentation: *The Secret of Mastery Learning: The Power Law of Human Performance (An Action Plan for Teachers & Allies).* By Diola Bagayoko. Audience: 35 teachers.

60. December 9, 2001. Auditorium, Forest Heights Elementary School, Baton Rouge, Louisiana. School Excellence Workshop. Presentation: *Avoiding or Closing Academic Achievement Gaps: An Action Plan for Teachers, Parents, Students, Schools and Others*. By Diola Bagayoko. Audience: 30 teachers.

59. November 9, 2001. Auditorium, Faculty (College) of Sciences and Technology, University of Mali, Bamako, Mali, West Africa. Conference presentation: *"La Loi de la Performance Humaine et ses*

Applications pour l'enseignement, l' apprentissage, et la recherche," By Diola Bagayoko. Audience: 1,100 students and 30 professors.

58. October 29, 2001. Cotonou, Benin , West Africa. 2nd International Symposium on Contemporary Problems in Mathematical Physics (COPROMATH2). Presentation: *A Mathematical Solution to the Band Gap Catastrophe*. By Diola Bagayoko, G. L. Zhao, Saleem Hasan. Audience: 40.

57. October 29, 2001. Cotonou, Benin , West Africa. 2nd International Symposium on Contemporary Problems in Mathematical Physics (COPROMATH2). Presentation: *Mathematical Physics Education: The Model of the Timbuktu Academy*. By Diola Bagayoko and Amadou Guisse'. Audience: 50

56. October 4-5, 2001. Jackson State University, Jackson Mississippi. The Tennessee State University AOL-Time Warner HBCU Digital Divide Conference. Presentation: *Reverse Digital Divide: A Case Study at the Timbuktu Academy and a Model for the Future*. By Diola Bagayoko. Audience: 140.

55. Environmental Technology Consortium Summit Conference; Technology Transfer: *Closing the Basic and Applied Research Divide*. Presentation: PIPELINES and the GLOBE Program. Audience: well over 50 faculty and staff members.

54. August 22, 2001. Louisiana State University-Geology Building. LA 2nd Annual Conference on Micro-fabrication and Materials Science. Presentation: *Ab-initio Calculation of the Electronic Structure of Carbon Nanotubes*, by D. Bagayoko, G. L. Zhao, and S. Hasan.

53. August 8-9, 2001. Gaithersburg, Maryland. National Institute of Standards and Technology (NIST) SURF Program Closing Symposium: Bagayoko chaired the second (on 8/8) and last (on 8/9) sessions. Audience: 64 student presenters, NIST Scientists and Administrators.

52. August 7, 2001. Auburn University, Auburn. Alabama. Sixth Applied Diamond Conference/Second Frontier Carbon Technology Joint Conference (ADC/FCT-2001). Presentation: *Ab-initio description and prediction of properties of carbon-based and other non-metallic materials*. D. Bagayoko, G. L. Zhao, and S. Hasan.

51. July 1-7, 2001. Singapore. International Conference on Materials for Advanced Technologies; Symposium on Materials Science Education. Presentation: *Basic and Advanced Training for the New Millennium: The Model of the Timbuktu Academy*-D. Bagayoko, R. Bobba, E. L. Kelley, and S. Hasan.

50. June 22-23, 2001. Sheraton Hotel, Baton Rouge, LA. Louisiana Partnership Conference for Parents, Teachers, and Schools, LA Department of Education. Presentation: *"A Rosetta Stone for Competitive Education: A Road-Map for Parents, Teachers, and School Administrators."* Audience: 150 parents, 100 teachers, and many school administrators.

49. June 18-19, 2001. Double Tree Hotel, Arlington, VA. NSF Conference on Partnerships: "*Building a Foundation for Innovations*." Approximately 100 participants. Intervention: Breakaway Session.

48. May 31, 2001. Radisson Hotel, Hampton, VA. Annual AME Conference: "*Reverse Digital Divide: A Case Study in the Department of Physics at SUBR*." Audience: 60 Participants.

47. May 1, 2001. Embassy Suites, Des Moines Iowa. Closing Ceremony of Science Bound. Presentation: "*Growing Toward Success*." Audience: 300 students, parents, and officials.

46. April 28, 2001. Ramada Inn Hotel, Baton Rouge, LA. Annual Leadership Conference of Phi Delta Kappa International Fraternity. Presentation: "*Addressing Academic Achievement Gaps*." Audience: over 50 parents and professionals.

45. April 24, 2001. Department of Physics, University of South Carolina, Columbia, SC. "*The Model of the Timbuktu Academy (From Causes to Effects).*" Audience: 15 faculty members and graduate students.

44. April 11, 2001. Forest Heights Elementary School, Baton Rouge, LA. Issue: Preparation for Field Trip to Houston. Audience: 20 Elementary Students, two Teachers, and the Principal.

43. April 11, 2001. Crestworth Middle School, Baton Rouge, Louisiana. Presentation: "*GLOBE and Educational Reforms*." Audience: 40 teachers, school administrators, and staff members.

42. April 9, 2001. Health Research Center, SUBR. Presentation: "*Developing Strategies for Parental Involvement in Support of GLOBE.*"

41. April 7, 2001. Crestworth Middle School, Baton Rouge, LA. Presentation: "*Hands-on, Mind-on GLOBE Activities*." Audience: 20 teachers, administrators, and staff members.

40. March 29, 2001. Lafayette School System Office, Lafayette, LA. Presentation: "*The GLOBE Program.*" Audience: 15 school administrators and science teachers.

39. March 23, 2001. Washington Hilton, Washington, D.C. 15th Annual NAFEO High Technology Student Expo. *"The Law of Performance and Excellence in Research."* 100 undergraduate students and 14 faculty members.

38. February 22, 2001. 6:30-7:30 PM. Phi Delta Kappa International, Educational Fraternity. Moore Hall Auditorium, SUBR. "*How to Prepare for Standardized Tests (LEAP and Others).*" Audience: 50 students and parents.

37. February 21, 2001. 2:45-3:45 PM. SU Laboratory School. *Benchmarks and Educational Reforms.* Audience: Thirty six (36) K-12th grade teachers and school administrators and staff members.

36. February 11-13, 2001. Annual DOE-EPSCoR and LS-LAMP Conference, New Orleans Radisson Hotel. "*Avoiding (or Closing) the Academic Achievement Gaps.* Audience: Over 100.

35. February 6-8, 2001. First Louisiana Reading Summit. Lafayette Hilton, Lafayette, Louisiana. *"The Genesis of Genius," A Scientific Explanation Of The Creation Of Educational Value Added From Pre-K To Graduate School And Beyond.* Audience: over 70 attended. Over 100 received viewgraphs.

34. February 5, 2001. "*The Global Learning And Observations To Benefit The Environment (GLOBE) As A Tool For The Implementation Of K-12th Grade Science, Mathematics, And Engineering Education Reform.*" Audience: 31 members of the Magnet Curriculum Committee of East Baton Rouge Parish School System.

33. January 27, 2001. 9 AM to 1 PM workshop on ACT preparation. Peabody Magnet High School, Alexandria, Louisiana. "*ACT English, Reading, Science Reasoning, and Mathematics*." Audience: Over 60 students from 9 AM to 1 PM.

32. January, 2001. Hawaii. Third International Conference on New Theories, Discoveries and Applications of Superconductors and Related Materials (NEW3SC-01), Hawaii. Presentation: "*Predicted Electronic Properties of Cubic* Si_3N_4." D. Bagayoko and G. L. Zhao.

31. January, 2001. Hawaii. Third International Conference on New Theories, Discoveries and Applications of Superconductors and Related Materials (NEW3SC-01), Hawaii. Presentation: "*Anomalous Isotope Effect in Narrow Band Superconductors.*" G. L. Zhao and D. Bagayoko.

30. October 21, 2000. Auditorium, School of Nursing, SUBR. SU Virtual Weekend Conference on Distance Learning. Presentation: "*GLOBE and Web Integration in Teaching and Learning-Precollege and Pre-service Education.*" Audience: 70.

29. October 18, 2000. Blue and Gold Room of the Student Union at Southern University and A&M College in Baton Rouge. Presentation on *"A Rosetta Stone for Competitive Education."*

28. Saturday, October 7, 2000. Dillard University, New Orleans, Louisiana. 9 AM-3 PM presentation on: *"Developing Responsive and Competitive (LEQSF) Enhancement Proposals."* Audience: 30. (Similarly on 09/23/00 from 1 PM to 5 PM; 09/14/00 from 1 PM to 5 PM.)

27. August 17-18, 2000. Advanced Materials Research Institute, University of New Orleans, Louisiana. Presentation: "*Materials Science Research and Education at SUBR.*" Audience: 80.

26. August 17-18, 2000. Advanced Materials Research Institute (AMRI), University of New Orleans, Louisiana. Presentation: "*The BZW Method for Accurate Calculations of Electronic and Related Properties of Semiconductors*." G. L. Zhao and D. Bagayoko. Audience: 70.

25. August 9, 2000. Blue and Gold Room, SUBR Student Union. A Presentation to the Explanation of Academic Achievement Levels Using the Law of Human Performance. D. Bagayoko on *"The Genesis of Genius."* Over Forty (40) pre-college students and parents.

24. July, 2000. International GLOBE Conference, Annapolis, Maryland. Presentation: "*Expanding GLOBE Participation: An Emerging Model for Diversification.*" R. L. Ford and D. Bagayoko. Audience: over 120 GOLBE teachers and scientists from around the world.

23. March 27, 2000. Annual DOE-EPSCoR and LS-LAMP Conference, Baton Rouge's Holiday Inn South. *"The Integrated Law of Human Performance, Mentoring, and You,"* D. Bagayoko. Audience: 100.

22. March 22, 2000. Orientation of Teachers for the Global learning and Observation to Benefit the Environment (GLOBE). *"A Rosetta Stone for Competitive Education,"* D. Bagayoko. Audience: 70.

21. March 21, 2000. March Meeting of the American Physical Society (APS), Minneapolis, MN. *"Predicted Electronic Properties of Cubic* Si_3N_4.*,"* D. Bagayoko and G. L. Zhao, Bull. Amer. Phys. Soc., March 2000. http://www.aps.org/meet/MAR00/baps/abs/S1780011.html

20. March 21, 2000. March Meeting of the American Physical Society (APS), Minneapolis, MN. *"Polaronic Effects in Ferroelectrics."* Y. M. Malozovsky, J. D. Fan, D. Bagayoko, and J. T. Wang. Bull. Amer. Phys. Soc., March 2000. http://www.aps.org/meet/MAR00/baps/abs/S5800007.html

19. March 24 2000. March Meeting of the American Physical Society (APS), Minneapolis, MN. *"Ab-initio Computations for the Absorption Edge of AlN."* Y. X. Luo, G. L. Zhao, and D. Bagayoko. Bull. Amer. Phys. Soc., March, 2000. http://www.aps.org/meet/MAR00/baps/abs/S8960007.html

18. March 24 2000. March Meeting of the American Physical Society (APS), Minneapolis, MN. "The BZW Method and the Electronic Properties of ZnSe." L. Torrence, G. L. Zhao, and D. Bagayoko. Bull. Amer. Phys. Soc., March 2000. http://www.aps.org/meet/MAR00/baps/abs/S8970006.html

17. March 21, 2000. March Meeting of the American Physical Society (APS), Minneapolis, MN. *"The BZW Method and Calculations for the Electronic Properties of Ge.*" G. L. Zhao and D. Bagayoko. Bull. Amer. Phys. Soc., March 2000. http://www.aps.org/meet/MAR00/baps/abs/S8150013.html

16. March 17, 2000. Annual Meeting of the National Society of Black Physicists and Annual, National Conference of Black Physics Students (NCBPS), Greensboro, NC. *" The Timbuktu Academy: The Science Of Creating Education, Research, And Professional Value Added."* D. Bagayoko (Audience: 30). *"Review of Mechanics."* D. Bagayoko. Audience: 40 students.

15. March 4, 2000. Annual, National, Mardi Gras Conference, Baton Rouge, Louisiana. *"Predictive Calculations of Electronic and Related Properties of Materials."* D. Bagayoko. Audience: 70.

14. February 16-20, 2000. National Summit on Africa, Washington, D.C., Bagayoko was an official Louisiana Delegate and a representative of the Southern University System.

13. February 15, 2000. Annual Meeting of the National Association for Equal Opportunity (NAFEO) in Higher Education, Washington, D.C., Hilton and Towers. *Session Chair* for students' technical presentations, NAFEO High Tech Expo. Speaker: *"Why to Attend Graduate School."* D. Bagayoko. (Audience: 100.)

12. February 12, 2000. Annual Conference of the Quality Education for Minority (QEM) Network, Washington, D.C., Panel presentation on *"Fundamentals of Mentoring and Networking."* D. Bagayoko.

11. June 25, 1999. SUBR Student Union, Southern University and A&M College-Baton Rouge. The 1999 National Meeting of the Council of Historically Black Graduate Schools (CHBGS). One hour, Invited Presentation: *"Graduate Research for the 21st Century."*

10. June 3, 1999. Circus Circus Hotel, Las Vegas, Nevada. Second International Conference on New Theories, Discoveries, and Applications of Superconductors and Related Materials (NEW^3SC-2). Invited Plenary Presentation: *"Predictive, Ab-initio Computations of Properties of Ferroelectric Material.,"* D. Bagayoko and G. L. Zhao. Audience: 120 physicists from around the world.

9. June 2, 1999. Circus Circus Hotel, Las Vegas, Nevada. Second International Conference on New Theories, Discoveries, and Applications of Superconductors and Related Materials (NEW^3SC-2). Presentation: *"Ab-initio Calculations for the Superconducting Properties of Yba2Cu3O7 (YBCO)."* G. L. Zhao and D. Bagayoko. Audience: 120 physicists from around the world.

8. May 8, 1999. New Orleans, Louisiana. NAACP Daisy Bates, National, Educational Symposium. Invited Presentation: *"Minorities in Science."* D. Bagayoko.

7. April 13-14, 1999. Pennington Center, Baton Rouge, Louisiana. *"Links for Success,"* Annual Statewide Conference of the Louisiana Experimental Program to Stimulate Competitive Research (EPSCoR), Chair and Speaker for the Session on *Materials (i.e., Research, Development, and Related Economic Potential).*

6. March 27, 1999. Atlanta, Georgia, Centennial Meeting of the American Physical Society. Presentation: *"Predicted Properties of 3C-SiC and 4H-SiC".* G. L. Zhao and D. Bagayoko. *Bulletin, American Physical Society, 1999.*

5. March 26, 1999. Atlanta, Georgia, Centennial Meeting of the American Physical Society. Presentation: *"Predictive Calculations of Electronic Properties of Semiconductors." D. Bagayoko, G. L. Zhao, and T. D. Williams. 3/26/99 Bulletin, American Physical Society, 1999.*

4. March 23, 1999. Grambling, Louisiana. Presentation: *"Developing a Responsive and Competitive BRSF Proposal."* A half-day workshop at Grambling State University.

3. March 22, 1999. Atlanta, Georgia, Centennial Meeting of the American Physical Society. Presentation: *"Calculated Properties of Ferroelectric BaTiO3."* D. Bagayoko, G. L. Zhao, J. D. Fan and J. T. Wang. Bulletin, American Physical Society, 1999.

2. March 21, 1999. Atlanta, Georgia, Annual Meeting for the National Society of Black Physicists (NSBP). Presentation: *"Predictive Calculations of Properties of Molecules, Clusters, and Semiconductors,"* D. Bagayoko, G. L. Zhao, and T. D. Williams.

1. March 6, 1999. School of Nursing Auditorium, Southern University and A&M College, Baton Rouge, Louisiana. Presentation: *"Mentoring, the Perspective of US Presidential Award Winners."* Presentation by Diola Bagayoko.

SUMMARY, NUMERICAL RESULTS OF THE TIMBUKTU ACADEMY
Southern University and A&M College in Baton Rouge (SUBR), Louisiana 70813

African American STEM Graduates Mentored by the Timbuktu Academy And Numbers Who Completed or Are in Graduate School												
Description	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**Totals**
Physics Alumni	12	6	10	8	10	8	4	7	1	2	6	**74**
Enrolled in/completed graduate school	11	3	8	7	8	6	1	4	1	2	4	**55**
Chemistry Alumni			3	2	6	5	2	1	4	5	5	**30**
Enrolled in/completed graduate school			2	0	5	2	0	1	4	3	2	**19**
Engineering Alumni	2	1	1	2	5	7	4	2	7	3	4	**34**
Enrolled in/completed graduate school				1	3	2	1	2	5	2		**16**
Total Number of Alumni	14	7	14	12	21	20	10	10	12	10	15	138
Number of Alumni in Graduate School	11	3	10	8	16	10	2	7	10	7	6	90

** 1994 Physics graduates Include 1992 and 1993 graduates. Chemistry students admitted into the Academy starting in 1993-94.*

Summer Pre-College Program Participants										
Program	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2004**	**Total**
Getting Smarter at the Timbuktu Academy (GeSTA)							20	34	10	**64**
Summer Science Institute - Middle School Component (SSI-M)	39	40	80	80	70	60	63	100	24	**556**
Summer Enrichment at the Timbuktu Academy (SETA)				24	22	18	27	20	17	**128**
Summer Science Institute (SSI)	40	53	39	23	21	19	20	8	22	**245**
Challenge 2000 at the Timbuktu Academy (Challenge 2000)				20	19	22	23	26	32	**142**
Earth Science at the Timbuktu Academy (ESTA)						28	21	8		**57**
Summer Bridge Institute (SBI)	25	25	24	13	14	13	19	13	11	**157**
GRAND TOTAL	**104**	**118**	**143**	**160**	**146**	**160**	**193**	**209**	**116**	**1349**

10 and 11 Challenge participants made National Merit or National Achievement in 2000 & 2001

Southern University and A & M College

Timbuktu Academy Graduates by Discipline through May 2005

Baton Rouge, Louisiana 70813

PHYSICS:

Name	SEX	Yr/Sem Grad.	Source of Support	# Of Grad.	Current Status
Kumah, Divine	M	Su04	ONR	74	(Su '04 Grand Marshall) Fall '04 –Grad. School at the University of Michigan (PhD- Applied Physics Program)
Sims, Gerard	M	Su04	NASA-USAR/ONR	73	Employed by Hartford Financial Services Group in Connecticut; Grad School in Fall Actuarial Sciences
Bershell, Carie	F	Sp04	ONR	72	Fall '04 Grad. School at SUBR (MS Physics Program)
Brown, Jr., Eugene	M	Sp04	ONR	71	Employed by Home Owners Loans – Baton Rouge, LA; Math/Science Middle School Teacher
Darensbourg, Brandon	M	Sp04	ONR	70	Employed by Altex Computers and Electronics in Houston, Texas
McKinsey, Rachel	F	Sp04	NASA-USAR/ONR	69	Fall '04 – Grad. School at University of Wisconsin at Madison (PhD-Medical Physics Program)
Pullen, Anthony	M	Sp04	NASA-USAR/ONR	68	(Sp '04 Grand Marshall) Fall '04 – Grad. School at CalTech (PhD – Theoretical Astrophysics)
Robinson, Jabari	M	Sp03	ONR	67	Fall '03-Grad. School at LSU (MS Physics Program)
Mosely, Trinesha	F	Sp03	ONR	66	Fall '03-Grad. School at Rice University (MS/PhD Applied Physics Program)
Ashenafi, Michael	M	Fa02		65	(Fall '02 Grand Marshall) Spring '03 – Grad School @ LSU(MS-Medical Physics)
Self, Vanessa	F	Fa01	ONR	64	Resource Teacher at Northeast H.S.; currently applying to Grad. Program at SUBR
Swilley, Michael	M	Su01	ONR	63	Employed by Entergy – St. Francisville, LA
Heard, Malcolm	M	Sp01	ONR	62	Fall '01 – Graduate school @ the University of Houston in Houston, TX (Medical Physics Program)
Jones, Philip	M	Sp01	ONR	61	Summer '03 – Grad. School @ University of South Carolina (PhD Physics Program); May '03- M.S. Physics earned @ SUBR
Tubbs, Kevin	M	Sp01	ONR	60	Fall '01 – Graduate school for PhD @ LSU-BR
Williams, Keisha	F	Sp01	ONR	59	Fall '01 – Graduate school @ Purdue University in West Lafayette, IN (MS Physics program)
Wilson, Karen	F	Sp01	ONR	58	Fall '01-High School Math Teacher –Lafayette, LA
Payne, Nathaniel	M	Su00	ONR	57	Passed away – sickle cell anemia
Cooper, Sarenee	F	Sp00	NASA-USAR	56	Enrolled in MS Medical Physics program at Georgetown University, Employed by the National Institute of Standards and Technology (NIST)- Radioactivity Group in Gaithersburg, MD
Millican, Michelle	F	Sp00	ONR	55	Employed by the National Institute of Standards and Technology as a Nuclear Physics Technician; Fall 2002, Enrolled in MS in Health Physics @ Georgetown University
Moncriffe, Branton	M	Sp00	ONR	54	Summer '03 – Grad. School for PhD @ University of South Carolina (PhD Physics Program); May '03- M.S. Physics earned @ SUBR
Wallace, Mark	M	Su99	ONR	53	In transition: Employed, but intends on graduate school after one year.
Bandele, Kafele	M	Sp99	ONR	52	Employed by Ameritech, but intends on graduate school

					after one year.
Crosby, Robert	M	Sp99	ONR	51	Summer '99 – Earned PhD, in Sci. Eng. University Florida at Gainesville
Grey, Jeremiah	M	Sp99	ONR	50	Fall '99 – Earned PhD in Sci. Eng (Fall 2004) of University of Florida at Gainesville
Lee, Benita	F	Sp99	ONR	49	As of 5/99, employed by Raytheon – Tucson, AZ; Currently enrolled in PhD program in Optics (Physics)- part-time @ Univ. of AZ
Shaw, NeShana	F	Sp99	ONR	48	Enrolled in MS Physics at SUBR Summer 2004
Stewart, Anthony	M	Sp99	ONR	47	Fall 2000 – Graduate school, University of Florida at Gainesville (Ph.D. Material Science program)
Wadley, Samara	F	Sp99	ONR	46	Fall '99 – Grad. School @ University of Kentucky, Lexington, KY - (MS Physics)
Ewing, Toni A.	F	Fa98	RCMS/ONR	45	Employed by Lockheed Martin– Denver, CO
Beathley, Louis	M	Su98	ONR	44	Fall '98-Grad. School @ SUBR-M.S. Physics; 8/2000 employed by Raytheon in Boston before completion of degree
Grant, Carl R.	M	Su98	ONR	43	Grad. School @ SUBR – Computer Science
Carter, Katrina	F	Sp98	ONR	42	Fall '98- MS degree in Medical Physics earned from Cornell
Day, Dana	F	Sp98	RCMS/ONR	41	Employed by Lucent Technologies – Power Systems Engineer – Atlanta, GA
Dodson, Tommy	F	Sp98	ONR	40	Sum. '99 – Grad. School @ SUBR - M.S. Physics
Hillard, Paul	M	Sp98	ONR	39	Earned MBA from Purdue University; currently employed by Hitachi, San Francisco, CA
Jackson, Jeremy	M	Sp98	ONR	38	Earned M.S. in physics from SUBR – 5/2000; currently pursuing PhD in physics @ Florida A & M University, Tallahassee
Mattox, Shinar	F	Sp98	ONR	37	Employed by Hewitt Associates Lincolnshire, IL
Torrence, Lashounda	F	Sp98	ONR	36	Earned M.S. in Physics from SUBR – 5/2001; currently employed with the Timbuktu Academy
Bryant, Elana	F	Fa97	RCMS	35	Spring '98-Grad. School @ Fisk University
George, Timothy	M	Fa97	RCMS	34	Earned JD in 2003 – 04
Lee, Monica	F	Fa97	RCMS	33	Employed by NASA' s Johnson Space Center – Houston, Texas
Young, Venetia	F	Fa97	ONR	32	Employed by Shell Oil Company-Texas; Currently applying to medical schools
Francis, LaKindra P.	F	Sp97	ONR/NIST	31	Completed M.S. in Physics @ SUBR – Su98. Employed by Raytheon Systems in New Orleans, LA; currently pursuing MBA
Horton, Holli	F	Sp97	RCMS	30	M. S. degree earned 12/99 Norfolk State University (NSU) – Currently employed at Corning in South Carolina
King, Veronica	F	Sp97	ONR	29	Employed by Raytheon Systems-L.A., CA; pursuing graduate degree
Muhammad, Kevin	M	Sp97	ONR	28	Earned JD @ SUBR
Franklin, Kaiana	F	Fa96	ONR/NIST	27	Raytheon Systems-Los Angeles, CA. Pursing graduate degree in Physics @ USC As of 2/99, employed by Comrise Technology – Hazlet, NJ.
Wesley, Lawrence	M	Fa96	ONR/NIST	26	Employed by Raytheon Systems-New Orleans, LA
Williams, Troy D.	M	Su96	NASA-USAR	25	Completed M.S. in Physics at SUBR – Su98; pursuing PhD @ SUBR in Science and Math Education (Summer 2001)
Adolph, Louis	M	Sp96	ONR	24	Employed by Pratt & Whitney – Florida, currently in Grad. School
Barlow, Lumumba	M	Sp96	ONR	23	Employed by Raytheon Systems- New Orleans
Dixon, LaShondria B.	F	Sp96	ONR/NIST	22	Completed M.S. in Physics @ SUBR – Su98; employed by Raytheon Systems

Dean, Andre	M	Sp96	NSF		Employed
Pillot, Bonique D.	F	Sp96	RCMS	21	Spring '99- Earned @ Tulane University – Public Health; in Medical School
Pillot, Ebonique C.	F	Sp96	RCMS	20	Spring '99 – Grad. School @ Georgia State University
Smith, Jr., Robert J.	M	Sp96	NASA-USAR	19	Employed by United Space Alliance, TX; Grad school @ University of Texas, Fall '98; earned graduate degree 5/2001.
Roberson, Monica	F	Fa95	RCMS	18	Employed by United Space Alliance, Texas
Wade, Watasha	F	Fa95	RCMS	17	Employed
Brisco, Melvin	M	Sp95	ONR	16	BS-PHYS-SUBR, MS-MATH & SCIENCE at Louisiana State University, Works at Georgia Pacific in LA
Prier, Donald	M	Sp95	RCMS	15	Employed in CA
Spear, Nathaniel	M	Sp95		14	Physics teacher – Pointe Coupee Central High School – P.C., LA
Williams, Kema	F	Sp95	NSF	13	Employed at Boeing in Houston, TX
Cox, Benny	M	Sp94	NSF	12	MS-Computer Science-North Carolina and A&T, Works at Naval Surface Warfare Center in Dahlgren, VA
Patterson, Edward	M	Sp94		11	M.S. Physics Degree earned @ SUBR – Fall 1998
Rockward, Tommy	M	Sp94	NSF/RCMS	10	M.S. Physics Degree earned @ SUBR; Employed by Los Alamos Nat'l Laboratory
Sheppard, Wilson	M	Sp94	NSF	9	M.S.@ Clark-Atlanta University
Jones, Steven	M	Sp93	ONR	8	Employed (Atlanta, GA)
Franklin, Dionne	F	Sp93	NSF	7	M.S. @ Kent State University Earned
Hampton, Chenita	F	Sp93	NSF	6	Ph.D. program @ Northwestern Univ.; M.S. in applied mathematics @ Georgia Tech. Earned
Vegara, Billy	M	Sp93	NSF	5	Naval Graduate School
Wilson, Daphne	F	Su92	NSF	4	M.S. (Computer Science) earned @ SUBR. Employed by MCI- Texas
Bell, Sharon	F	Sp92	ONR	3	Entrepreneur
Jeffrey, Milton	M	Sp92	NSF	2	Grad. Degree @ Navy Nuclear Submarine Program (M.S.)
Wallace, Denesia	F	Sp92	NSF	1	M.S.- Environmental Chemistry @ SUBR

Summary of Physics Graduates:

- **Number of Graduates – 74**
- **Number Pursuing Graduate Degree – 53**

Southern University and A & M College

Timbuktu Academy Graduates by Discipline through May 2005

Baton Rouge, Louisiana 70813

CHEMISTRY:

Name	SEX	Yr/Sem Grad.	Source of Support	# of Grad.	Current Status
Casey, David	M	Sp04	NASA-USAR/ONR	26	Fall 04' Tulane Medical School
Stewart, Kyana	F	Sp04	ONR	25	Fall '04 – University of Florida at Gainesville, FL (PhD-Environmental Engineering Program)
Chaney, Joseph	M	Sp03	ONR	24	To be determined
Hubert, Leroy	M	Sp03	ONR	23	Fall '03-enrolled at Baylor University of Medicine
Walker, Don	M	Sp03	ONR	22	Fall '03 – Grad. School @ CalTech (PhD Chemistry Program)
Walker, Ron	M	Sp03	ONR	21	Fall '03-Grad. School @ CalTech (PhD Chemistry Program)
Millican, Jasmine	F	Su02	ONR	20	Fall '02- Grad. School @ LSU for Ph.D. in Chemistry, Baton Rouge, LA
Thomas, Evan	M	Su02	ONR	19	Fall '02- Grad. School @ LSU for Ph.D. in Chemistry, Baton Rouge, LA
Daniels, Chauncey	M	Sp02	ONR	18	Fall '02-Grad. School @ University of N. Texas Health & Science Center, Fort Worth, TX
Pierre, Monique	F	Sp02	ONR	17	Fall '02-Grad. School @ IUPUI, Indianapolis, Indiana
Green, Kellie	F	Sp01	ONR	16	Fall '01 – Graduate school @ Purdue University
Jones, Deanna	F	Fa99	ONR	15	Employed in scientific industry
Adams, Mistie	F	Sp99	ONR	14	NIH: Postbaccalareate Intramural Research Training Award
Harris, Kinesha	F	Sp99	ONR	13	Fall'99- Grad. School @ Univ.of Iowa
Holmes, Veronica	F	Sp99	ONR	12	Fall'99-Grad. School @ University of Nebraska; currently @ LSU
Johnson, Rolanda	F	Fa98	ONR	11	Earned Ph.D., Chemistry, LSU- Baton Rouge
Jones, Conrad	F	Fa98	ONR	10	Earned Ph.D., Chemistry 2005
Negatu, Selam	F	Fa98	ONR	9	Fall'99 – Grad. School @ Georgia State University
Thomas, Kimberly	F	Fa98	ONR	8	B.S.Chemistry; pursuing second B.S Chemical Engineering @USL
Warrington, Leah	F	Fa98	ONR	7	Program Administrator: DOE-Samuel P. Massie Chair of Excellence prog.–SUBR
Shaw, Vincent	M	Sp98	ONR	6	Fall '98- Enrolled in Medical School
Jenkins, Kyndra	F	Sp97	ONR	5	Seventh grade science teacher at Grand Bay Middle School Mobile, AL
Swain, Tomi	F	Su97	ONR	4	In Transition to a graduate program Fall '01
Thomas, Gloria	F	Fa96	ONR	3	Graduate school @ LSU; earned Ph.D. Faculty

					member, Univ. of MS
Jackson, JoAnne	F	Sp96	ONR	2	Enrolled in medical school @ Creighton
Nelson, Laurie	F	Sp96	ONR	1	Employed by CINTEL – Orlando, FL

Summary of Chemistry Graduates:

- **Number of Graduates – 26**
- **Number Pursuing Graduate Degree – 19**

Southern University and A & M College

Timbuktu Academy Graduates by Discipline through May 2005

Baton Rouge, Louisiana 70813

ENGINEERING:

Name	SEX	Yr/Sem Grad.	Source of Support	# of Grad.	Current Status
Jones, Sherman	M	Fa04	ONR	1	Employed by ExxonMobil in Houston, Texas
Whitlock, Rogers	M	Fa04	ONR	2	Engineer, Boeing, Chicago
Dixon, Candice	F	Sp03	ONR	3	Engineer, Northrop Grumman, Newport News, VA
Mizell, Symoane	F	Sp03	ONR	4	Fall '03-Grad. School at Stanford University
Jackson, Winston	M	Sp03	ONR	5	Fall '03-Grad. School at University of Illinois at Urbana-Champaign
Pace, Spencer	M	Fa02	ONR	6	Senior Engineer, Texas Instrument, Dallas, TX
Joseph, Jacob O. Jr.	M	Su02	ONR	7	In transition: Applying to graduate programs
Gant, Valdez	M	Sp02	ONR	8	Employed by Texas Instruments (Fa02-Sp03); Plans to pursue Ph.D. in EE at Georgia Tech (Fall 2003)
Hutcherson, Sarne	M	Sp02	ONR	9	Fall '02-Grad. School @ Georgia Tech for MS in ME
Marshall, Adrian	M	Sp02	ONR	10	Fall '02-Grad. School @ Georgia Tech
McKinney, Shannon	F	Sp02	ONR	11	Employed by Pratt & Whitney in West Palm, FL; planning to obtain MS in Mat'l Science and/or MBA through P&W Fellowship
McKinsey, Joshua	M	Sp02	ONR	12	Fall '02 – Grad. School @ Georgia Tech (MS in ME), Atlanta, GA
Cassimere, Brandon	M	Sp01	ONR	13	Fall '01 – Graduate school @ Purdue University
Cassimere, Brant	M	Sp01	ONR	14	Fall '01 – Graduate school @ Purdue University
Adkins, Clarence	M	Su00	ONR	15	Fulfilling Naval Obligation
Love, Thurmasia	F	Sp00	ONR	16	Employed by the Department of Defense in Warner Robins, GA
Truxillo, Audis	M		ONR	17	In transition
Hill, Christina	F	Fa99	ONR	18	Employed by IMS Engineers in Jackson, MS
Pitcher, Vernon	M	Fa99	ONR	19	Employed by Agilent Technologies
Smith, Tiffini	F	Su99	ONR	20	Fall '99 – Graduate school @ Purdue University
Holland, Jamal	M	Sp99	ONR	21	Employed by General Motors
Mixon, Kanika	F	Sp99	ONR	22	Enrolled in graduate school @ LSU
Skanklin, Thereza	F	Sp99	ONR	23	Employed by United Space Alliance – Texas
Stampley, Caroline	F	Sp99	ONR	24	Employed by Exxon – Baytown, TX
Davis, Angela	F	Fa98	ONR	25	Employed by Delphi – Clinton, MS
Davis, Bartholomew	M	Fa98	ONR	26	Employed
Hubert, Ingrid	F	Fa98	ONR	27	Reliant Energy HL&P (Houston Lighting and Power) – Houston, Texas; pursuing MBA at Houston Baptist Univ.- Spring 2000
Williamson, Tameka	F	Fa98	ONR	28	Employed by Allied Signal – Kansas City, MO; also, pursuing MBA and MIS @ Webster

					University
Pitre, III, Alton	M	Su98	ONR	29	Employed by Army Corp; planning to enroll part-time to graduate school
Mitchell, Donovan	M	Fa97	ONR	30	Employed by National Security Agency
Abernathy, Michael	M	Sp97	ONR	31	Graduate degree earned @ LSU
Donald, Petrenia	F	Fa96	ONR	32	Entrepreneur
Powell, Gerald	M	Fa95	ONR	33	Employed by Ford Motor Co. B.S.; currently employed by Pratt & Whitney – Connecticut
Sims, Debra	F	Fa94	ONR	34	Employed by Texas Instruments, Dallas, TX
Thomas, Marcus	M	Fa94	ONR	35	Employed by Chrysler Corporation

Summary of Engineering Graduates:

- **Number of Graduates – 35**
- **Number Pursuing Graduate Degree – 13**

Southern University and A & M College

Timbuktu Academy Graduates by Discipline through May 2005

Baton Rouge, Louisiana 70813

MATHEMATICS:

Name	SEX	Yr/Sem Grad.	Source of Support	# of Grad.	Current Status
Walton, Eric	M	Sp03	ONR	1	Employed at Johnson & Johnson in New Brunswick, NJ

Summary of Mathematics Graduates:

- **Number of Graduates – 1**
- **Number Pursuing Graduate Degree – 0**

Southern University and A & M College

Timbuktu Academy Graduates by Discipline through May 2005

Baton Rouge, Louisiana 70813

BIOLOGY:

Name	SEX	Yr/Sem Grad.	Source of Support	# of Grad.	Current Status
Thomas, Kenya	F	Sp04	ONR	1	
Gennuso, Sonya	F	Sp05	NASA-USAR/ONR	2	Enrolled in Graduate School at Louisiana State University (LSU)

Summary of Biology Graduates:

- **Number of Graduates – 2**
- **Number Pursuing Graduate Degree – 1**

Summer 1998 Research Sites: Off-Campus

Scholar	Class/Major	Location
1. Mistie Adams	Sr.-Chem.	Yale University
2. Genine Black	Sr.-Chem.	British Petroleum
3. Katrina Carter	B.S.-Sp98-Phys	NASA Goddard Space Flight Center
4. Kimberly Carter	So.-Chem./ChE	Conoco – Lafayette, LA
5. Brandon Cassimere	Jr.-EE	Exxon – Baton Rouge, LA
6. Brant Cassimere	Jr.-EE	Exxon – Baton Rouge, LA
7. Kenyon Coleman	Jr.-Phys	University of Kentucky
8. Sarenee' Cooper	Jr.-Phys	Lawrence Livermore National Laboratory – Livermore, CA
9. Robert Crosby	Sr.-Phys	Cornell University – Ithaca, NY
10. Angela Davis	Sr.-EE	International Business Machines (IBM) – Austin, TX
11. Bartholomew Davis	Sr.-EE	Micro Switch (Honeywell) – Freeport, IL
12. Tommy Dodson	B.S.-Sp98-Phys	Shell Services International – Houston, TX
13. Toni Ewing	Sr.-Phys	Louisiana State University – Baton Rouge, LA
14. Jeremiah Grey	Sr.-Phys	Northwestern University – Evanston, IL (CIC-SROP)
15. Malcolm Heard	So.-Phys/Math	Lawrence Livermore National Laboratory – Livermore, CA
16. Christina Hill	Sr.-CE	LA Alliance for Minority Participation (LAMP)/LSU – Baton Rouge
17. Paul Hilliard, III	B.S.-Sp98-Phys	Lawrence Livermore National Laboratory – Livermore, CA
18. Veronica Holmes	Sr.-Chem.	University of Nebraska – Lincoln, NE
19. Jamal Holland	Sr.-ME	Pratt & Whitney – West Palm Beach, FL
20. Jeremy J. Jackson	B.S.-Sp98-Phys	Lawrence Livermore National Laboratory – Livermore, CA
21. Rolanda Johnson	Sr.-Chem.	BASF – Geismer, LA
22. Philip Jones	So.-Phys	National Nanofabrication… (Cornell University) – Ithaca, NY
23. Benita Lee	Sr.-Phys/Math	Princeton Plasma Physics Laboratory – Princeton, NJ
24. Thurmasia Love	Sr.-CE	Solo (Procter & Gamble) – New Orleans, LA
25. Monikka Mann	Sr.-Phys	Los Alamos National Laboratory – Los Alamos, NM
26. Michelle Millican	Jr.-Phys	Lawrence Livermore National Laboratory – Livermore, CA
27. Kanika Mixon	Sr.-ME	Goodyear Tire and Rubber Company – Akron, OH
28. Branton Moncriffe	Jr.-Phys	BREC-LSU-BRAS Observatory – Baton Rouge, LA
29. Darrin Monroe	Sr.-E.E.	Lucent Technologies – NJ
30. Selam Negatu	Sr.-Chem.	Los Alamos National Laboratory – Los Alamos, NM
31. Vernon Pitcher	Sr.-E.E.	Delphi Saginaw Steering Systems (GM) – Saginaw, MI
32. Thereza Shanklin	Sr.-M.E.	Novartis Crop Protection – Geismer, LA
33. NeShana Shaw	Sr.-Phys	Princeton Plasma Physics Laboratory – Princeton, NJ
34. Roy Sims	Jr.-M.E.	Hewlett Packard
35. Tiffani Smith	Sr.-EE	General Motors (GM) – Detroit, MI
36. Caroline Stampley	Sr.-M.E.	Exxon – New Orleans, LA
37. Anthony Stewart	Sr.-Phys	International Business Machines (IBM) – NY
38. Tracee Thomas	Sr.-Chem./ChE	Texaco Oil Company – New Orleans, LA
39. Audis Truxillo	Sr.-EE	Lucent Technologies – Chicago, IL
40. Kevin Tubbs	So.-Phys	University of Oklahoma
41. Samara Wadley	Sr.-Phys	University of Kentucky
42. Keisha Williams	So.-Phys	Cornell University – Ithaca, NY
43. Tameka Williamson	Sr.-M.E.	Boeing – Wichita, KS

Summer 1999 Research Sites

Scholar	Class/Major	Location
1. Mistie Adams	B.S.-Sp99-Chem.	NIH: Postbacculatreate Intramural Research Training Award
2. Clarence Adkins	Sr.-ME	Naval Cruise Ship
3. Eugene Brown,II	Jr.-Phys.	Lawrence Livermore National Laboratories- Livermore, CA
4. Kimberly Carter	Jr.-Chem./Ch.E.	Conoco-New Orleans, LA
5. Brandon Cassimere	Sr.-EE	Exxon-Baton Rouge, LA
6. Brant Cassimere	Sr.-EE	Exxon-Baton Rouge, LA
7. Kemisha Coleman	Sr.-Phys.	University of Kentucky, Lexington, KY
8. Kenyon Coleman	Sr.-Phys.	University of Kentucky, Lexington, KY
9. Sarenee Cooper	Sr.-Phys.	National Institute of Standard Technology – Gaithersburg, MD
10. Robert Crosby	B.S.-Sp99-Phys.	Graduate School –Florida State University
11. Angela Davis	B.S.-Fa98-EE	Delphi – Clinton, MS
12. Wayne Dyer, Jr.	So.-Phys.	Research Assistant - PIPELINES
13. Jeremiah Grey	B.S.-Sp99-Phys.	Lucent Technologies – Princeton, NJ
14. Kinesha Harris	B.S.-Sp99-Chem.	Lawrence Livermore National Laboratory- Livermore , CA
15. Malcolm Heard	Jr.-Phys.	MIT – Boston MA
16. Christina Hill	Sr.-Civil E.	ITOHM Mediation Services - Hawaii
17. Jamal Holland	B.S.-Sp99-M.E.	General Motors
18. Veronica Holmes	B.S.-Sp99-Chem.	Department of Energy –Morgantown, West Virginia
19. Ingrid Hubert	B.S.-Fa98-	Reliant Energy – Houston, TX
20. Sarne Hutcherson	So-ME	Hewlett-Packard
21. Rolanda Johnson	B.S.-Fa98-Chem.	LSU – Baton Rouge, LA
22. Conrad Jones	B.S.-Fa98-Chem.	Iowa University – Iowa City, Iowa
23. Deanna Jones	Sr.-Chem.	SUBR
24. Philip Jones	Sr.-Phys.	Princeton Materials Institute – Princeton, NJ
25. Jacob Joseph, Jr.	So-ME	Counselor for Summer Programs of the Timbuktu Academy
26. Benita Lee	B.S.-Sp99-Phys.	Raytheon Systems – Tucson AZ
27. Thurmasia Love	Sr.-Civil E.	INEEL- Idaho Falls, Idaho
28. David Mallett	So-Phys.	University of Houston - Houston, TX
29. Michelle Millican	Sr.-Phys.	Lawrence Livermore National Laboratory- Livermore, CA
30. Branton Moncriffe	Sr.-Phys.	NASA- Lewis-Cleveland, OH
31. Darrin Monroe	Sr.-EE	Lucent Tachnologies – Murray Hill, NJ
32. Spencer Pace	So-EE/Math	Michigan Technological University – Houghton, MI
33. Vernon Pitcher	Sr.-EE	Lucent Technologies – Chicago, IL
34. Brandis Rawls	So-Phys.	NASA Lewis –Cleveland, OH
35. Vanessa Self	Jr.-Phys.	Lockheed Martin –Oakridge, TN
36. Thereza Shanklin	B.S.-Sp99-ME	United Space Alliance – Texas
37. NeShana Shaw	B.S.-Sp99-Phys.	Lucent Technologies – Princeton, NJ
38. Roy Sims	Sr.-ME/Math	Deplhi – Kokomo, Indiana
39. Caroline Stampley	B.S.-Sp99-ME	Exxon- Baytown , TX
40. Anthony Stewart	B.S.-Sp99-Phys.	National Institute of Standards and Technology–Gaithersburg, MD
41. Travis Thierry	So.-Phys.	SMART Program@Southern University and A & M College
42. Kimberly Thomas	B.S.-Fa98-Chem.	LSU- Baton Rouge, LA
43. Kevin Tubbs	Jr.-Phys.	Lawrence Livermore National Laboratory –Livermore, CA
44. Samara Wadley	B.S.-Sp99-Phys.	INEEL –Idaho Falls, Idaho
45. Wesley Wells	So.-Chem.	LAMP @ SUBR
46. Keisha Williams	Jr.-Phys.	National Institute of Standards and Technology – Gaithersburg, MD
47. Tameka Williamson	B.S.-Fa98-	Allied Signal – Kansas City, MO

52. Jeremy McCormick	Jr./EE	Iowa State University - Des Moines, IA

*Affiliate Scholar

Summer 2000 Research Sites

Scholar	Location
1. Michael Ashenafi*	University of Alabama - Birmingham, Alabama
2. Cari Bershell	Louisiana State University - Baton Rouge, Louisiana
3. Eugene Brown	Louisiana State University - Baton Rouge, Louisiana
4. Kimberly Carter	Global Learning and Observation to Benefit the Earth (GLOBE)
5. Brandon Cassimere	Exxon Mobil - Baton Rouge, LA
6. Brant Cassimere	Exxon Mobil - Baton Rouge, LA
7. Raven Charles	SMART (SUBR) - Baton Rouge, LA
8. Sarenee' Cooper	National Institute of Standards and Technology - Gaithersburg, MD
9. Chauncey Daniels	National Renewable Energy Lab - Golden, Colorado
10. Rhonda Davis	SMART Research Program (SUBR) - Baton Rouge, LA
11. Delveatra DeVance	SMART Research Program (SUBR) - Baton Rouge, LA
12. Candice Dixon	Procter and Gamble - Cincinnati, Ohio
13. Kara Franklin	NASA Stennis Space Center - Stennis Space Center, MS
14. Joubert Harris	U. S. Department of Agriculture - Watkinsville, Georgia
15. Malcolm Heard	National Institute of Standards and Technology - Gaithersburg, MD
16. Sarne Hutcherson	Hewlett-Packard Company - Vancouver, Washington
17. Philip Jones	Stanford University -
18. Jacob Joseph, Jr.	Delphi Automotive Systems - Sandusky, Ohio
19. Adrian Marshall	Michigan Technological University - Houghton, MI
20. Marx Mbonye*	University of Michigan - Ann Arbor, Michigan
21. Shannon McKinney	Hewlett-Packard - Vancouver, Washington
22. Joshua McKinsey	Stennis Space Center - Stennis Space Center, MS
23. Jasmine Millican	Louisiana State University (LAMP Program) - Baton Rouge, LA
24. Michelle Millican	National Institute of Standards and Technology - Gaithersburg, MD
25. Symoane Mizell	SMART Research Program (SUBR) - Baton Rouge, LA
26. Branton Moncriffe	MIT Lincoln Laboratory - Lexington, MA
27. Jackie Mouton II	USDA - J. Phil Cambel Research Center - Watkinsville, GA
28. Deborah Muhammad	Global Learning and Observation to Benefit the Earth (GLOBE)
29. Spencer Pace	General Motors - Fort Wayne, Indiana
30. Monique Pierre	Louisiana State University (LAMP Program) - Baton Rouge, LA
31. Brandis Rawls	CAMD - Baton Rouge, LA
32. Mary Sims	SMART Research Program (SUBR) - Baton Rouge, Louisiana
33. Roy Sims	Exxon
34. Evan Thomas	USDA-ARS, Watkinsville, GA
35. Keisha Thomas	Stennis Space Center - Stennis Space Center, MS
36. Melinda Thompson	XEROX
37. Kevin Tubbs	California Institute of Technology (SURF) - Livingston, LA
38. Keisha Williams	California Institute of Technology (SURF) - Livingston, LA
39. Karen Wilson	CAMD - Baton Rouge, LA

*Affiliate Scholar

*Affiliate Scholar CE=Civil Engineering EE=Electrical Engineering ME=Mechanical Engineering

Summer 2001 Research Sites

Scholar	Class/Major	Location
1. Michael Ashenafi*	Jr./Physics	University of Alabama at Birmingham - Birmingham, AL
2. Cari Bershell	So./Physics	National Institute of Standards & Technology-Gaithersburg, MD
3. Van Brass II	So./Biology	USDA-APHIS-VS - Gainesville, FL
4. Creshaundra Burns	Fr./Chemistry	SMART-REU, Baton Rouge, LA
5. Brandon Cassimere	BS-Sp01-EE	Exxon - Baton Rouge, LA
6. Brant Cassimere	BS-Sp01-EE	Exxon - Baton Rouge, LA
7. David Casey	Fr./Physics	Stanford University - Stanford, CA
8. Raven Charles	So./Physics	Virginia Tech - Blacksburg, VA
9. Chauncey Daniels	Jr./Chemistry	University of North Texas Health Science Center- Forth Worth, TX
10-. Brandan Darensbourg	Jr./Physics	National Institute of Standards & Technology-Gaithersburg, MD
11. Rhonda Davis	So./Physics	Marshall Space Center - Huntsville, AL
12. Candice Dixon	Jr./EE	PIPELINES (Earth Science Research)-SUBR, Baton Rouge
13. Kara Franklin	So./EE	Raytheon - Dallas, TX
14. Valdez Gant	Sr./EE	Delphi Delco Electronics Systems - Kokomo, IN
15. Sonja Gennuso	Fr./Physics	University of Michigan - Ann Arbor, MI
16. Sarne Hutcherson	Jr./ME	Delphi Delco Electronics Systems - Kokomo, IN
17. Winston Jackson	So./CE	URE for Tomographics...Louisiana State Univ. - Baton Rouge
18. Philip Jones	BS-Sp01-Phys	Grad. Research Excellence at the Timbuktu Academy- SUBR
19. Sherman Jones	Fr./ME	Exxon Mobil Corporation - Baytown, TX
20. Jacob Joseph, Jr.	Jr./ME	Delphi Delco Electronics Systems - Sandusky, OH
21. Moussa Keita	Jr./Cmp.Sc.	PIPELINES-Earth Science Research-SUBR, Baton Rouge
22. Adrian Marshall	Jr./EE	General Motors - Milford, MI
23. Marx Mbonye*	Jr./Physics	University of Michigan-CERN, France and Switzerland
24. Shannon McKinney	Jr./ME	Hewlett-Packard - Vancouver, Washington
25. Joshua Mckinsey	Jr./ME	Ford Motor Company - Cleveland, OH
26. Rachel Mckinsey	Fr./Physics	MIT- Boston, MA
27. Jasmine Millican	Jr./Chemistry	University of Illinois - Chicago, IL
28. Symoane Mizell	So./CE	National Institute of Standards & Technology-Gaithersburg, MD
29. Trinesha Mosely	Jr./Physics	Lucent Technologies Bell Laboratories - Murray Hill, NJ
30. Jackie Mouton II	So./Physics	Marshall Space Center - Huntsville, AL
31. Deborah Muhammad	Jr./Physics	PIPELINES, Earth Science Research - SUBR
32. Ivan Myers, Jr.	Fr./Physics	Purdue University - West Lafayette, IN
33. Shelli Pace	Fr./Physics	Center for Advanced Microstructures & Devices B.R., LA
34. Spencer Pace	Sr./EE	Agilent - Denver, CO
35. Monique Pierre	Jr./Chemistry	IUPUI - Indianapolis, IN
36. Jabari Robinson	So./Physics	Lawrence Livermore National Laboratory - Livermore, CA
37. Kyle Sanford	Fr./EE	Michigan Technological University - Houghton, MI
38. C. Gerard Sims	Fr./Physics	University of Michigan - Ann Arbor, MI
39. Mary Sims	So./Chemistry	IUPUI - Indianapolis, IN
40. Kia Smith	Fr./Physics	Purdue University - West Lafayette, IN
41. Kyana Stewart	Fr./Chemistry	Abbott Laboratories - Chicago, IL
42. Evan Thomas	Jr./Chemistry	Nation Renewable Energy Lab (NREL) - Golden, CO
43. Keisha Thomas*	Sr./Cmp.Sc.	Stennis Space Center - Stennis Space Center, MS
44. Kenya Thomas	Fr./Biology	Northoaks Laboratory - Hammond, LA
45. Don Walker	So./Chemistry	BASF - Geismer, LA
46. Ron Walker	So./Chemistry	Texaco - Houston, TX
47. Erica Walton	So./Math	The University of Iowa - Iowa City, Iowa
48. Rogers Whitlock	So./EE	Michigan Technological University - Houghton, MI
49. Anthony Wilborn	Jr./EE	Kraft Foods - Detroit, MI
50. Kimberly Wright	So./EE	Delphi Delco Electronics Systems - Kokomo, IN
51. Joseph Chaney*	Sr./Chemistry	University of Massachusetts - Amhurst, MA

Summer 2002 Research Sites

Scholar	Class/Major	Location
1. Michael Ashenafi*	Sr./Physics	CERN/University of Michigan - Geneva, Switzerland
2. Michael Baham	Fr./Physics	LIGO - Livingston, LA
3. Cari Bershell	Jr./Physics	National Institute of Standards and Technology - Gaithersburg, MD
4. Van Brass II	Jr./Biology	
5. Creshaundra Burns	So./Chemistry	Chevron - Belle Chase, Baton Rouge, LA
6. David Casey	So./Physics	Stanford University (SURF) - Palo Alto, CA
7. Mariol Charles	Fr./ME	Michigan Technological University - Houghton, MI
8. Raven Charles	Jr./Physics	Iowa State University - Ames, IA
9. Chauncey Daniels	BS-Sp02-Chem	University of North Texas Health Science Center - Forth Worth, TX
10. Brandan Darensbourg	Sr./Physics	National Institute of Standards and Technology - Gaithersburg, MD
11. Candice Dixon	Sr./EE	Louisiana Biomass Council/SUBR - Baton Rouge, LA
12. Aliah C. Dugas	Fr./Chemistry	University of Michigan - Ann Arbor, MI
13. Valdez Gant	BS-Sp02-EE	Delphi Delco Electronics Systems - Kokomo, IN
14. Sonja Gennuso	So./Physics	NASA Ames Research Center - Moffett Field, CA
15. Rhondalyn Geralds	Fr./Chemistry	HBCU-UP SMART (SREU)/SUBR - Baton Rouge, LA
16. Latasha Henry	So./EE	Michigan Technological University - Houghton, MI
17. Sarne Hutcherson	BS-Sp02-ME	Timken - Canton, OH
18. Winston Jackson	Jr./CE	Department of Energy/Bechtal SAIC - Las Vegas, NV
19. Thomasas Jernigan	Jr./Chem-ChE.	Louisiana State University (REU) - Baton Rouge, LA
20. Sherman Jones	So./ME	Exxon Mobil Corporation - Baytown, TX
21. Moussa Keita*	Sr./Cmp.Sc.	PIPELINES-Earth Science Research-SUBR, Baton Rouge, LA
22. Divine Kumah*	Fr./Physics	National Renewable Energy Lab (NREL) - Golden, CO
23. Adrian Marshall	BS-Sp02-EE	Texas Instruments - Sherman, TX
24. Marx Mbonye*	Sr./Physics	Goddard Space Flight Center - Greenbelt, MD
25. Jeremy McCormick*	Sr./EE	University of Kentucky - Lexington, KY
26. Shannon McKinney	BS-Sp02-ME	Pratt & Whitney - Florida
27. Joshua McKinsey	BS-Sp02-ME	Dow Chemical - Plaquemine, LA
28. Rachel McKinsey	So./Physics	National Institute of Standards and Technology - Gaithersburg, MD
29. Symoane Mizell	Jr./CE	Louisiana State University - Baton Rouge, LA
30. Arthur Monroe, Jr.	Fr./Chemistry	University of Michigan - Ann Arbor, MI
31. Trinesha Mosely	Sr./Physics	Lucent Technologies Bell Laboratories - Murray Hill, NJ
32. Jackie Mouton II	Jr./Physics	Marshall Space Center - Huntsville, AL
33. Ivan Myers, Jr.	So./Physics	NASA Ames Research Center - Moffett Field, CA
34. Shelli Pace	So./Physics	National Institute of Standards and Technology - Gaithersburg, MD
35. Monique Pierre	BS-Sp02-Chem	IUPUI - Indianapolis, IN
36. Lakelle Pritchett	Fr./CE	HBCU-UP SMART (SREU)/SUBR - Baton Rouge, LA
37. Anthony Pullen	Fr./Physics	Massachusetts Institute of Technology - Cambridge, MA
38. Jabari Robinson	Jr./Physics	Tulane University (LAMP) - New Orleans, LA
39. Kyle Sanford	So./EE	Michigan Technological University - Houghton, MI
40. Tina Shelvin	Fr./CE	HBCU-UP SMART (SREU)/SUBR - Baton Rouge, LA
41. C. Gerard Sims	So./Physics	Smithsonian Astrophysics Observatory (SAO) - Cambridge, MA
42. Mary Sims	Jr./Chemistry	Exxon Mobil - Chalmette, LA
43. Kia Smith	So./Physics	NASA Ames Research Center - Moffett Field, CA
44. Kyana Stewart	So./Chemistry	Abbott Laboratories - Abbott Park, IL
45. Kenya Thomas	So./Biology	National Institute of Standards and Technology - Gaithersburg, MD
46. Douglas Toussaint	So./ME	Exxon Mobil - Baton Rouge, LA
47. Don Walker	Jr./Chemistry	California Institute of Technology - Pasadena, CA
48. Ron Walker	Jr./Chemistry	California Institute of Technology - Pasadena, CA
49. Erica Walton	Jr./Math	National Institute of Standards and Technology - Gaithersburg, MD
50. Rogers Whitlock	Jr./EE	Georgia Institute of Technology - Atlanta, GA
51. Anthony Wilborn	Jr./	Merck Pharmacueticals- Philadelphia, PA
52. Kimberly Wright	So./EE	Georgia Institute of Technology - Atlanta, GA

Summer 2003 Research Sites

Scholar	M/F	Class/Major	Location
1. Aliah C. Dugas	F	Sr./Chemistry	NASA Ames, Moffett Field, CA
2. Sonja Gennuso	F	Sr./Physics	NASA Ames Research Center, Moffett Field, CA
3. Lotherine Gimblin	F	So./ME	DOW Chemicals, Plaquemine, LA
4. Amber Hall	F	Sr./Microbiology/Minor Chemistry	Northwestern University SROP, Evanston, IL
5. Quintina Hardesty	F	Sr./Mathematics	University of Houston – REU Houston, TX
6. Brandi Henderson	F	Sr./Architecture	University of Illinois at Urbana Champaign-SROP, Champaign, IL
7. Latasha Henry	F	Sr./EE	Delphi Corporation, Kokomo, IN
8. DeAnna Hudson	F	Jr./EE	Delphi Corporation, Kokomo, IN
9. S. Teala Johnson	F		SUBR – SMART
10. Leslie Jones	F	Jr./Biology	Brown University (intern), RI Hospital (research), Providence, RI
11. Theryl Jones	F	Sr./EE	Caterpillar, Inc., Peoria, IL
12. Genese Knox	F		Attended summer school at SUBR
13. Rachel McKinsey	F	Sr./Physics	University of Kentucky Medical center's Radiation Medicine Department, Lexington, KY
14. Symoane Mizell	F		Graduated Sp. 03
15. Trinesha Mosely	F	Graduated Sp.03	Lucent Technologies, Murray Hill, NJ
16. Shelli Pace	F	Jr./Physics	University of North Carolina, Chapel Hill, NC
17. Krystal Oates	F	Jr./Mathematics	LSU – Environmental Research
18. Anisha Scott	F	Sr./Biology	SUBR – SMART
19. Kia Smith	F	Jr./Physics	NASA Ames, Moffett Field, CA
20. Kenya Thomas	F	Sr./Biology	SROP/McNair program at University of Chicago, Il
21. Shalindria Thomas	F	So./Biology	Clark Atlanta University, Atlanta, GA
22. Erica Walton	F	Graduating Sr.	Johnson & Johnson Corporate Headquarters, New Brunswick, NJ
23. Kimberly Wright	F	Sr./EE	University of Illinois at Urbana Champaign-CIC SROP, Urbana, IL
24. Iheanyi Akujobi	M	Jr./Chemistry	UCLA, NSF Solid State Chemistry, University of Arkansas
25. Michael Baham	M	Jr./Physics	Harvard-Smithsonian Center for Astrophysics, Cmabridge, MA
26. Bobby Burches	M	Sr./Chemistry	Merck Research Labs, Philadelphia, PA
27. David Casey	M	Sr./Physics	SUBR
28. Johnathan Goins	M	Sr./	General Motors, Shreveport, LA
29. Daniel Hart	M	So./Physics	Lawrence-Berkley National Laboratory
30. Michael Jackson	M		LSU-CAMD
31. Winston Jackson	M	Sr./CE	Graduated Sp. 03
32. Sherman Jones	M	Sr./ME	Exxon Mobil, Baytown, TX
33. Moussa Keita	M	Graduating Sr.	PDSI, LSU, PM- Doctoral Scholars Institute
34. Divine Kumah	M	Sr./Physics	CERN, Switzerland
35. Trindell Major	M	Sr./	Exxon Mobil, Houston, TX
36. Marx Mbonye	M	Sr./Physics	NASA Goddard Space Center, Maryland
37. Arthur Monroe, Jr.	M	Jr./Chemistry	Tulane University – LAMP
38. Lawrence Mosley	M	So. /EE	LSU – CAMD
39. Ivan Myers	M	Sr./Physics	NASA Ames
40. David Nash	M	So./	Waterways Experiment Station, Vicksburg, MS
41. Keyonn Pope	M	Sr./EE	General Motors Electro-Motive Division, LaGrange, IL
42. Anthony Pullen	M	Sr./Physics	NASA – JPL, Pasadena, CA
43. C. Gerard Sims	M	Sr./Physics	NASA Ames, Moffett Field, CA
44. Harold Smith	M		Naval Research Lab, Washington, DC
45. Adam Zachary	M	Graduating Sr.	UIC – SROP

CE=Civil Engineering EE=Electrical Engineering ME=Mechanical Engineering

2004 SUMMER RESEARCH SITE

NO	NAME	CLASS/MAJOR	SITE
1.	Baham, Michael	Jr./Physics	Harvard- Smithsonian Center for Astrophysics, Cambridge, MA
2.	Blakes, Jr., Henry	Sr./Physics	Argonne National Laboratory, Chicago, IL.
3.	Burns, Creshaundra	Sr./Chemistry	Conoco Phillips (Lake Charles Refinery), Lake Charles, LA
4.	Darensbourg, Brandon	Grad. Sr./Physics	Argonne National Laboratory, Chicago, IL.
5.	Dugas, Aliah	Sr./Chemistry	NASA Ames Research Center, Moffett Field, CA
6.	Gennuso, Sonja	Sr./Biology	NASA Ames Research Center, Moffett Field, CA
7.	Hudson, DeAnna	Jr./EE	Delphi Delco, Kokomo, IN
8.	McKinsey, Rachel	Grad/Physics	University of Wisconsin, Madison, WI
9.	Mosely, Lawrence	Jr./EE	Texas A & M University, College Station, TX
10.	Pullen, Anthony	Grad/Physics	California Institute of Technology, Pasadena, CA
11.	Senegal, Chris	Jr./EE	Canadian National Transportation, Engineer Division (Co-op), [not confirmed]
12.	Sims, C. Gerard	Grad/Physics	NASA Ames Research Center, Moffett Field, CA
13.	Stewart, Kyana		
14.	Thomas, Kenya	Grad. Sr./Physics	Summer School at LSU, Baton Rouge, LA
15.	Thomas, Shalindria	Jr./Biology	University of Texas at Austin, Austin, TX
16.			
17.			
18.			
19.			
20.			

CE=Civil Engineering EE=Electrical Engineering ME=Mechanical Engineering

Fr.=Freshman So=Sophomore Jr.=Junior Sr.=Senior Grad=Graduated Spring 2004

Conference Attendance by Undergraduate Scholars of the Timbuktu Academy												
Conference Participation	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**Totals**
Number of conferences	5	8	10	9	5	6	5	6	19	15	2	88
Number of students attending	58*	34*	126*	67*	11	65*	97*	89*	15*	15*	4	581*
Number of students presenting	12*	5	9	14*	0	1	3	16*	3	4*	1	68*

**Not necessarily distinct students as some students attend more than one conference.*

THE BLACK COLLEGIAN®
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Second Semester (February) 2005
The Career & Self-Development Magazine for African-American Students

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Career Reports: Actuary • Engineering • Military

PLUS:

- Nobel Peace Prize Winners: Drs. Martin Luther King Jr. and Ralph J. Bunche
- The Murder of Emmett Till
- The Timbuktu Academy
- Jamie Foxx
- Rev. Al Sharpton and "I Hate My Job"

TOP 100 EMPLOYERS/AFRICAN AMERICAN HISTORY ISSUE

THE TIMBUKTU ACADEMY

The Genius Factory at Southern University

By Kojo Livingston

"Give me any kid who can walk and talk and they can become a Nobel Prize winner in Physics." Considering the current state of education in the United States, this is the kind of boast that could bring chuckles…unless you can back it up.

Dr. Diola Bagayoko made the above statement, and he doesn't joke about education. Dr. Bagayoko is the founder of the Timbuktu Academy, a national model program for mentoring pre-college, undergraduate, and graduate students in Science, Math, Engineering and Technology based at Southern University at Baton Rouge, La.

Since 1990, the Timbuktu Academy has won Presidential Awards from two different administrations and the Office of Naval Research has invested over $6 million in his program over a 10-year period, the latest grant amounting to nearly $1 million. The program is a virtual magnet for academic awards and citations.

But it's the science of lifelong learning that Dr. Bagayoko raves about. This science is of major importance to anyone desiring to become an effective teacher, parent or student. And Dr. Bagayoko is quick to stress that high achievement in education IS science, "Anyone can be made into an intellectual giant, (a genius)!"

Dr. Bagayoko was born in Mali, where he had formal training in the theory and practice of Teaching and Learning. He earned a BS degree in Physics and Chemistry from Mali's Ecole Normale Superieure in 1973. Bagayoko came to the US in 1978, the same year that he received his Master's degree in Solid State Physics. His Ph.D. was earned from Louisiana State University, Baton Rouge, La, in 1983, one year before he began teaching physics at Southern in the same city. He is currently a professor of physics and Chancellor's fellow at Southern.

The Timbuktu Academy is named after the former University of Timbuktu, the famous center of world scholarship in the middle of the last millennium. The University of Timbuktu, in Mali, West Africa, is located on the banks of the majestic Niger River. The Timbuktu Academy on the campus of Southern University in Baton Rouge, La. is likewise located on the banks of a mighty river, the Mississippi river.

The Genius Factory

Proximity to a river is not the only similarity between the two institutions. Like its namesake, the Timbuktu Academy is churning out overachievers. The program has already received two US Presidential Awards for Excellence in Mathematics, Science, and Engineering Mentoring for its work with creating opportunities for participation by women, minorities, and disabled persons in science, math, and engineering from the elementary through graduate levels.

Dr. Diola Bagayoko

The Academy's objectives are to produce first-class minority scientists and engineers who pursue Ph.D. degrees; to produce, organize, and disseminate knowledge through research, publications, and presentations; and to render professional services to the educational, corporate, and academic communities.

To date, the Academy has mentored nearly 1,000 pre-college students, helped over 120 attain bachelor's degrees and helped more than 70 people achieve graduate degrees, with an emphasis on doctorates. It is now a given that students who complete one of the Academy's summer or after-school programs dramatically raise their standardized test scores.

Spreading the science of achievement is a priority. That's why Timbuktu has an annual outreach to more than 5000 students, teachers, counselors, and administrators. This outreach happens through presentations, consultations and also via the numerous published articles by Dr. Bagayoko and his staff. His work and the Timbuktu Paradigm are documented in several professional publications.

Bagayoko is already well along the road to establishing Timbuktu-type programs across the nation. Currently there are 11 sites applying the Timbuktu Paradigm in Louisiana through the Louis Stokes-Louisiana Alliance for Minority Participation (LS-LAMP). Since 1995 LS-LAMP has been working to increase the number and quality of minority students earning undergrad degrees in science, technology, engineering, and mathematics (STEM) disciplines.

Led by Timbuktu at Southern in Baton Rouge, LS-LAMP comprises eleven col-

Timbuktu Scholars Weigh in on "The Academy"

Rachel McKinsey:
I was given the opportunity to spend a summer at NIST. My mentor took time to see what my interests were. Once I told her, she told me about a Medical Physicist, and had me to shadow one at the local hospital. After that meeting and research on what a Medical Physicist responsibilities are, I knew what I aspired to become. I have just completed my first semester in the Ph.D. program to become a Medical Physicist at the University of Wisconsin Madison.

Nita Clark, *a senior at Baton Rouge Magnet High School:*
I attended The Academy the summer before my senior year. They scared us into learning! They upped the grading scale so that a "C " was like an "F." So though we had class from eight in the morning to eight at night, you would find people studying well into midnight. The staff did a good job teaching us not just English but African-American history as well. I was picked as a National Achievement Semifinalist. All the time I was there I did nothing but whine and complain about how much I didn't like it. But now that I'm gone I really miss it.

Winston P. Jackson:
I joined the Academy in my sophomore year in undergrad at SU and remained until I graduated in May of 2003. The program really inspired me to undertake research opportunities in engineering. It helped to better my communication skills through mandatory writing assignments as well as presenting at conferences. Currently, I am a doctoral student at the California Institute of Technology. I credit this program for helping to bridge the gap in the lack of African-American professors in science and engineering.

Jeremiah Abiade:
I participated in the Summer Bridge Institute. A stipend was provided along, with tuition, room, and board. Besides the technical knowledge, the most valuable asset was an unwavering confidence in my abilities and myself. The emphasis on community service and leadership is greatly responsible for the leadership roles I have had. I have been president of the graduate student organization and received several community service awards. I just finished my Ph.D. in materials science and engineering at the University of Florida (Dec. 2004). I will be working as a postdoctoral researcher at North Carolina A&T State University. I would like to establish another mentoring program based on the paradigm that has been successfully demonstrated by Dr. Bagayoko.

Robert Crosby:
I became a scholar immediately after graduating from High School in 1995. The financial support and the constant pushing of one's self (to intern at major companies, governmental labs, and larger universities; to present research; to attend conferences, etc.) enlightened me to the tremendous rewards of being an African-American professional scientist. Actually I successfully defended my Ph.D. dissertation (in the Materials Science & Engineering Dept. at the University of Florida) two days ago, and in two weeks, I will start a new career as a Process Engineer for a device fabrication facility at Intel.

been pivotal. Several Rear Admirals have also supported the Academy in person. In particular, Rear Admiral Gaffney, former director of ONR, delivered an inspiring commencement speech at SUBR at the invitation of the Academy and the University. Rear Admiral Ann Rondeau visited SUBR twice in 2004. These visits were part of her genuine efforts to build and reinforce collaborations and partnership between the Navy and minority serving universities like SUBR. Finally, in December 2004, Rear Admiral Melvin G. Williams, Jr., spoke to the Scholars of the Academy of managing priorities as opposed to time, as the former should determine the allocation of the latter. The local Navy supporters of the Academy include Captain Sapp, the Commander of the Navy ROTC, and his staff. Bagayoko regularly notes the above support to the scholars to signify that not only failing is not an alternative for the Academy, but nothing less than the best will adequately merit this enriching support.

In Louisiana, many officials have been supporting the Timbuktu Academy and its sister program, LS-LAMP, in addition to SUBR. In particular, the Academy enjoys the substantial support of the Honorable Mary Landrieu, US Senator, and of her staff. For the last two years, she and her staff have been instrumental in ensuring that funds were available, through the Navy, to continue the implementation and dissemination of the national, exemplary model program the Timbuktu Academy is. The Commissioner of Higher Education in Louisiana, Dr. Joseph Savoie, is a champion supporter of the Academy and of LS-LAMP, according to Dr. Bagayoko.

Spread the Word, Close the Gap

The rapid doubling of the world's body of knowledge makes effective, lifelong learning both available and mandatory for survival or success. Yet there is an undeniable gap between those who achieve and those who don't.

Bagayoko is passionate and driven in his quest to eliminate the achievement gap. He wants to show the world that learning is possible for anyone who uses a proven, scientific approach.

"We are starting a learning revolution. We intend to eliminate the totally false concept that some are born to learn and others are not. I hope that through proven, documented efforts such as ours, ridiculous myths about education will go by the wayside. We can lift education to a high level for everyone regardless of gender, race, or class.

"We have already proven that the availability of high achievement through mentoring and quality teaching is no longer just a theory. It's a reality, a scientifically proven reality!"

Kojo Livingston *is a staff writer for THE BLACK COLLEGIAN Magazine.*

The Timbuktu Academy *can be reached by telephone at (225) 771-2730, by fax at (225) 771-4341, by e-mail at* ***Bagayoko@aol.com****, and on the web:* ***http://www.phys.subr.edu/timbuktu.htm.***

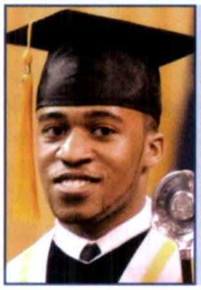
Timbuktu Academy Hall of Fame

Student Grand Marshals

Billy Vegara
Fall 1992 Student Grand Marshal
Navy ROTC Scholar

Michael Ashenafi
Physics Graduate
Spring 2002 Grand Marshal
Currently pursuing doctorate in medical physics at Louisiana State University

Kimberly Wright
Engineering Graduate
Fall 2003 Grand Marshal
Currently employed with Raytheon



Anthony Pullen
Physics Graduate
Spring 2004 Grand Marshal
Currently pursuing doctorate in physics at the California Institute of Technology

Divine Kumah
Physics Graduate
Summer 2004 Grand Marshal
Currently pursuing doctorate in applied physics at the University of Michigan

Jonathan Goins
L.S. LAMP Scholar
Engineering Graduate
Fall 2004 Grand Marshal
Currently attending Purdue University

Pre-College Scholars win at the National NOBCChE Science Bowl Competitions 2003, 2004, 2005

April 17-19, 2003 Indianapolis, Indiana

First Place - Senior Division

Yonas Yemane, junior, Baton Rouge High
Leisa Lawson, junior, Baton Rouge High
Brittani Ware, junior, Baton Rouge High
Nicholas Crawley-Brown, sophomore, University High

The team went undefeated throughout the competition, defeating a LaJolla, California team in the finals.

April 12-17, 2004 San Diego, California

First Place Winners - Senior Blue Team

Yonas T. Yemane, senior, Baton Rouge High
Leisa Lawson, senior, Baton Rouge High
Britani Ware , senior, Baton Rouge High
Nicholas Crawley-Brown , junior, University High

The Senior Blue team had a repeat first place victory at the National Competition.

March 20- 25, 2005 Orlando, Florida

First Place- Junior Division:

Spencer Carter, Glascow Middle
Tayla Duncan, University High
Devin Guillory, Glascow Middle
Miracle Johnson, University High
Justin Jefferson, University High

Second Place - Junior Division:

Jillian Crawley-Foster, University High
Kristoff Gager, McKinley High
Justin Paul, Baton Rouge Magnet High
Austin Winslow, University High
Ashley White, St. Joseph's Academy

Second Place - Senior Division:

Patrick Carriere, Baton Rouge Magnet High
Vincent Carter, McKinley High
Chris Ware, Baton Rouge Magnet High
Terrence Woods, McKinley High

Third Place - Senior Division

Nicholas Brown, University High
Aaron Gebrelul, Baton Rouge Magnet High
Naomi Gebrelul, Baton Rouge Magnet High
Silmon Gebreyessus, Baton Rouge Magnet High
Leah Machen, Baton Rouge Magnet High

Timbuktu Academy: Mentoring Future Scientists

CLINTON PARKS
MISCINET WRITER
UNITED STATES
6 MAY 2005

Because of Diola Bagayoko's (pictured left) expertise in educational theory and physics, his wife thought that he would be the perfect person to help undergraduates, especially African-Americans and other underrepresented minorities at Southern University in Baton Rouge, Louisiana, start their careers in science, technology, engineering, and mathematics (STEM).

Established in 1990 with funding from the National Science Foundation (NSF) and the Louisiana Board of Regents, the Timbuktu Academy is an award-winning mentoring program for underrepresented minorities in STEM fields.

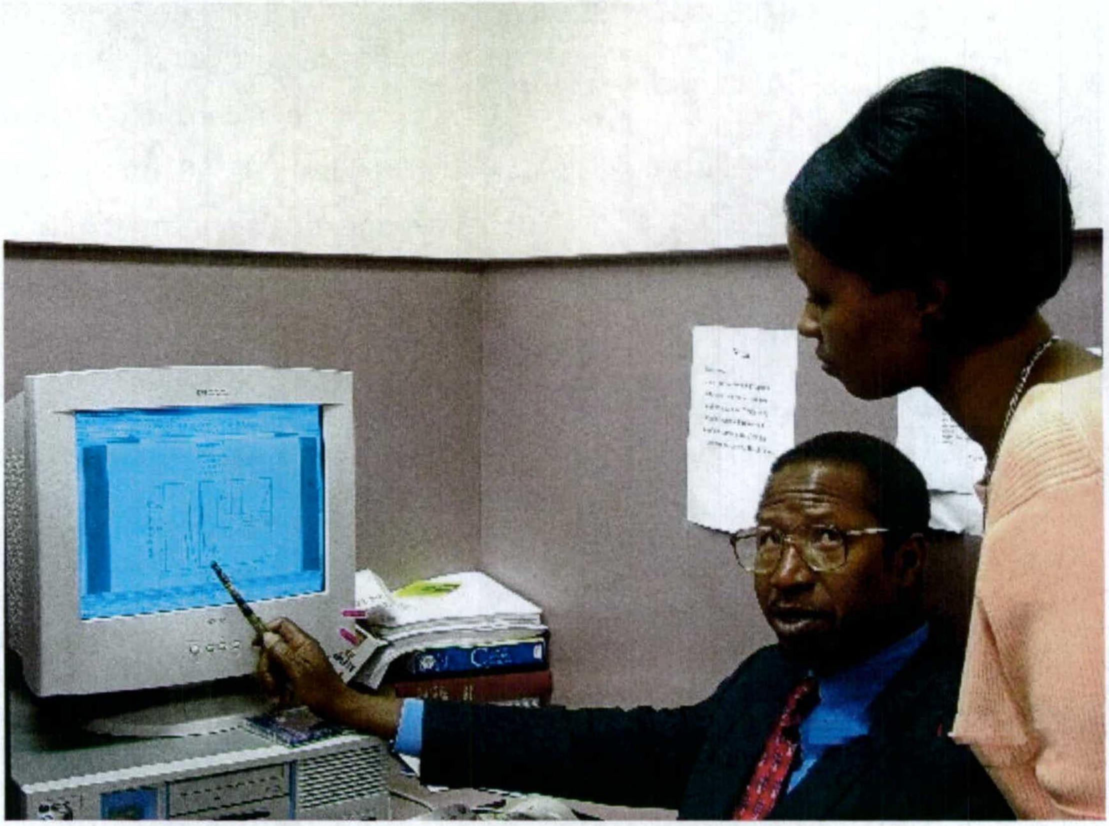
RELATED ARTICLES

Established in 1990 with funding from the National Science Foundation (NSF) and the Louisiana Board of Regents, the Timbuktu Academy is an award-winning mentoring program for underrepresented minorities in STEM fields. The program's pre-college to graduate curricula includes the Undergraduate Research Program (URP), which provides students with the educational support they need to succeed in graduate school. Bagayoko, a solid-state physicist and native of Mali, named the academy after the medieval Malian city of Timbuktu, which was renowned for its scholarship.

In the beginning, Timbuktu Academy provided mentoring only for physics undergraduates and a handful of pre-college students, but with the help of additional funding from the and a handful of pre-college students, but with the help of additional funding from the Department of the Navy and the Office of Naval Research (ONR), in 1993 the academy added chemistry and engineering majors and 100 to 200 pre-college students. To date, the academy's URP has sent 74 students—47 in physics—to science and engineering graduate programs throughout the country, including the University of Michigan, Stanford, and Cal Tech. Moreover, 19 have earned M.S. degrees and 8 have earned Ph.D.s with many others nearing completion.

Molding Young Minds

Bagayoko received his B.S. in physics and chemistry at the Ecole Normale Supérieure de Bamako, in Mali in 1973. While there he also studied educational theory and practice as a part of his general undergraduate education. He received his M.S. in solid state physics in 1978 from Lehigh University in Bethlehem, Pennsylvania, and his Ph.D. in theoretical solid state physics from Louisiana State University in Baton Rouge, Louisiana, in 1983.



Bagayoko helps a student.

After coming to the U.S. and joining Southern University's Department of Physics, he and academy co-director, Ella Kelley, combed the cognitive, behavioral, and experimental psychology literature to find a systematic-based mentorship model. The result—what they call "the Rosetta stone of learning"—is the Power Law of Human Performance by Newel and Rosenbloom (1981; To learn more see "Philosophical Foundations for Systemic Mentoring at the Timbuktu Academy"). "Anytime the individual performs a task, physical or mental, that individual improves at performing said task," says Bagayoko. "Any student who does not suffer from a severe physiological mental impairment can be trained and molded into a researcher."

The academy's undergraduate program has 50 spots available, so incoming Southern University freshmen interested in applying to the program must meet a minimum set of requirements. Besides listing an intention to major in physics, chemistry, or engineering, they must receive a minimum score of 24 on the ACT assessment exam (equivalent to 1090 to 1120 on the SAT). Admission to the URP isn't restricted to freshmen. Students who have completed a year at Southern in the aforementioned majors with at least a 3.0 GPA are also eligible. Once in the program, participants must maintain a 3.0 GPA.

The Academy's Steps to Success

According to Bagayoko, the "Ten-Strand Systemic Mentoring Model" (see box) enables the academy to facilitate superior academic performance, and provides a road map for a successful S&E career.

The Ten-Strand Systemic Mentoring Model
For more information, see the Timbuktu Academy Web site.

1. **Financial support**assures students have access to the university and the time available to devote to study and research full-time.
2. **Communication skills enhancement** provides students with activities to master technical communication skills (listening, speaking, reading, and writing).

master technical communication skills (listening, speaking, reading, and writing).

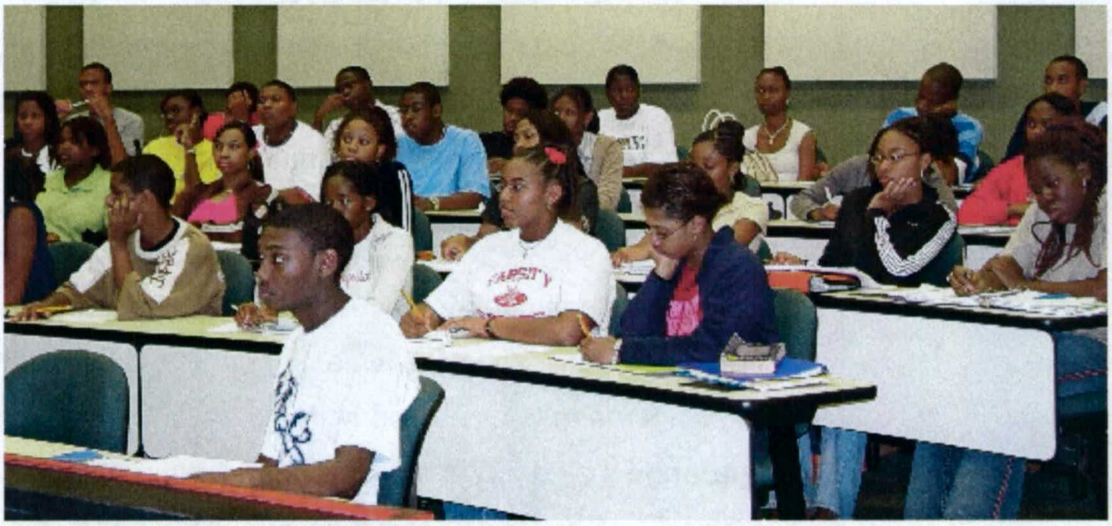
3. **Comprehensive, scientific advisement** is mandatory to ensure students take the proper sequence of courses and stay on task with personal goals.
4. **Tutoring** by faculty members and by peers is to establish excellence by addressing knowledge deficits and solidifying known concepts.
5. **Generic research activities** teach students how to master various types of literature searches and other research related skills.
6. **Specific research project execution** occurs in the summer and the academic year at academic, government, and industrial laboratories to prepare students for graduate studies.
7. **Immersion in a professional culture** demands staying abreast of ethics, the latest data published in technical journals and professional magazines, collaborating with colleagues, and attending conferences and seminars.
8. **Enhancement of computer and technological skills** encourages the mastery of word-processing, spreadsheets, databases, graphics, programming languages (C++, FORTRAN, etc.), and other applications.
9. **Monitoring** verifies the progress of students and averts potential problems (i.e., extra tutoring or dropping a course to avoid a bad grade).
10. **Guidance to graduate school** starts freshman year with GRE preparation, and is the culmination of the URP experience.

The Timbuktu Academy is dependent on its mentors to ensure its students meet objectives. Mentor coordinators at Southern identify and manage these mentors, at research institutions across the world, who in turn work to ensure a productive research experience for participating students.

The Undergraduate Research Program

Weekly seminars—given by students, invited guests, and faculty—are the backbone of the URP and help the students hone their speaking skills. The written assignments, which stress technical writing, help students perfect their scientific writing skills.

Due to limited resources on campus, URP students are encouraged to do summer research elsewhere. Bagayoko says, "One learns research by doing summer research elsewhere. Bagayoko says, "One learns research by doing research. By the time scholars graduate from here, at a minimum, they have had two summer research experiences." But he is quick to point out that most will have three and sometimes four research internships. Likewise, participation in local, state, and national conferences is also required. Participating in conferences is seen as a critical step in immersing oneself in the professional STEM culture by introducing students to new research, ideas, networking opportunities, and current developments within the field.



Timbuktu Academy students attending seminar.

Yielding Results

The Timbuktu Academy method has yielded impressive results. Between 1994 and 2001, URP students attended and presented at 54 national conferences. They regularly secure summer internships at prominent institutions like the National Institute of Standards and Technology, the Lawrence Livermore National Laboratory, the European Laboratory for Particle Physics, Johnson & Johnson, and Argonne National Laboratory. Several students have published papers in scientific journals with their off-campus summer mentors.

The academy's success has been recognized. In 2002, the Academy won the U.S. Presidential Award for Excellence in Science, Mathematics, and Engineering. Six years earlier, in 1996, Bagayoko received the U.S. Presidential Award for Excellence in Mentoring. But an even better indication of the program's success is that programs are lining up to copy the Timbuktu Academy model. Since 1995, ten Louisiana campuses have modeled similar programs on the URP with funding from the Louis Stokes Louisiana Alliance for Minority Participation (LS-LAMP). Jeremiah Gray, a postdoc at North Carolina A&T State University in Greensboro and a 1999 URP graduate, has contacted Bagayoko about replicating the Academy system there. The academy will soon implement two new programs—the "Freshman Experience at Southern University" (for all incoming freshmen) and a preparation program for the Naval ROTC—to further the goals of the Academy.

Ultimately, the academy's Undergraduate Research Program's success is because Bagayoko knows what it means to be a mentor. "To mentor properly does not mean to clone yourself," he says. "It means to inform, to support, to challenge a student, to monitor, to make sure things are well. But it also means making a student enter into functional networks," he continues. These networks include researchers on other campuses, student groups, and professional organizations. "I go to great lengths to make sure I'm not turning all of them into solid state theorists."

Clinton Parks is a writer for MiSciNet and may be reached at cparks@aaas.org.

The editors suggest these related resources at Nextwave:

- **Houston Colleges Boost Minority Participation in STEM Fields**
  Edna Francisco, 18 February 2005, UNITED STATES

- **Following My Curiosity**
  Terri Wright, 17 December 2004, UNITED STATES

Terri Wright, 17 December 2004, UNITED STATES

- **Philosophical Foundations for Systemic Mentoring at the Timbuktu Academy**
  Diola Bagayoko, 28 June 2002, UNITED STATES

From Here To Timbuktu

Dreams of achievement: Dr. Bagayoko, Timbuktu Academy strive for success at Southern University

By Kendra Toussant

"Race, gender nor socioeconomic status determines a student's performance. As a matter of fact, give me *any kid* that can walk and talk and they can be a Nobel Prize winner in physics."

These words are straight from the mouth of Dr. Diola Bagayoko, founder of Southern University's Timbuktu Academy; and when it comes to education, Bagayoko is all talk and all action.

The Timbuktu Academy is a nationally recognized program for mentoring pre-college, undergraduate and graduate students in the subjects of science, math, engineering, English and technology. The program was established in 1990, after co-director Ella Kelley–Bagayoko's wife of 24 years–made the suggestion that they should do something to help the students at Southern. He said, "She said, 'Diola, you should put your intellectual ability to work to help youth and minorities in general, with their educational problems at Southern University.'"

Since its establishment, the Timbuktu Academy has won accolades for excellence in mathematics, science and engineering mentoring. It is also recognized for its work in creating opportunities for women, minorities and disabled persons in science, math and engineering from elementary through graduate levels. The program has received a total of $6 million in federal grants from the Department of the Navy and the Office of Naval Research, with the amount of the latest grant being $1 million. The program has also received funding from the National Science Foundation, the National Aeronautics and Space Administration, Exxon-Mobil Foundation, Hewlett Packard Company and the National Institute of Standards and Technology.

According to Bagayoko, the program has also received funding from the Louisiana Board of Regents, through the Louis Stokes Louisiana Alliance for Minority Participation and the Louisiana Stimulus for Excellence in Research.

Dr. Bagakoyo attributes the program's success to the many sponsors and said he is grateful for all the help. "You can not do anything without money," he said. "This program has been successful because of all the funding."

The Timbuktu Academy is named after the former University of Timbuktu, a bastion of scholarship dating back to the middle of the last millennium, in the city of Timbuktu. The University of Timbuktu, which is in Mali, West Africa, is located on the left bank of the Niger River. Taking after its predecessor, the Timbuktu Academy on the campus of Southern University in Baton Rouge, is located on the left bank of the mighty River. Dr. Bagayoko says the academy is second to no other program.

The Academy's objectives are to produce first-class minority scientists and engineers who pursue doctoral degrees; to produce, organize and disseminate knowledge through research, publications and presentations; to render professional services to the educational, corporate and academic communities; and to bridge the academic achievement gaps separating, different ethnic groups, females and males, socioeconomic groups, states and countries.

To date, the Timbuktu Academy has mentored over 1,300 pre-college students and has helped over 130 to attain bachelor's degrees. Approximately 70 percent of the chemistry and physics graduates and 50 percent of engineering graduates successfully pursued or are pursuing graduate degrees, with an emphasis on a Ph.D. Bagayoko said that recent studies show that students who complete one of the Academy's summer or after school programs improve their standardized test scores.

"By participating in the program I learned so much about test-taking strategies and I had many opportunities to do research. The Timbuktu Academy aims to expose students to various opportunities," said Lashounda Franklin, a previous scholar and Dr. Bagayoko's assistant.

The program has an annual outreach to more than 5000 students, teachers, counselors and administrators. This outreach is possible through presentations, consultations and numerous published articles written by Bagayoko and his staff comprised of many of his colleagues, and previous and present Timbuktu scholars. "We did an extensive review of

all available literature on the learning process. Any system you can name, we studied it and took the best from each. This community helped us identify the laws and principles upon which the Timbuktu Academy is based," Bagayoko said.

Bagayoko also said that it is not an accident that scholars and affiliate scholars of the Academy have been student grand marshals of SUBR (tops of their graduation classes), fall 2003, spring 2004 and summer 2004. The Academy also has alumnae who have been former campus queens, indicating that educational excellence and elegance blend well. Some scholars feel that the Academy provided great learning opportunities and encouraged them to work harder.

"I was given the opportunity to spend a summer at NIST (National Institute of Standards and Technology). My mentor took time to see what my interests were. Once I told her, she told me about a medical physicist and had me to shadow one at the local hospital," Rachel McKinsey said.

Others say the academy benefited them greatly and helped them accomplish goals. Robert Crosby, a Timbuktu scholar added, "I became a scholar immediately after graduating from high school in 1995. The financial support and the constant pushing of one's self enlightened me to the tremendous rewards of being an African-American professional scientist." ■

For more information on the Timbuktu Academy at Southern University, visit www.phys.subr.edu/timbuktu.htm or call (225) 771-2730.

Timbuktu, also spelled TOMBOUCTOU, is a city in the West African nation of Mali. It is historically important as a post on the trans-Saharan caravan route. It is located on the southern edge of the Sahara, about 8 mi (13 km) north of the Niger River. Timbuktu was a centre for the expansion of Islam, an intellectual and spiritual capital at the end of the Mandingo Askia dynasty (1493–1591) and home to a prestigious Koranic university. Three great mosques that were built during this period, using traditional techniques, still remain.

Timbuktu was founded around AD 1100, first as a seasonal camp by Tuareg nomads. Soon after it was incorporated within the Mali Empire, probably in the late 13th century. The Mali sultan, Mansa Musam, built a tower for the Great Mosque (Djingereyber) and a royal residence, the Madugu (the former has since been rebuilt many times, and of the latter no trace now remains). Shortly afterward this the city was annexed by the Mossi kingdom of Yatenga, but when the North African traveller Ibn Battutah visited in 1353, he found it again governed by Mali.

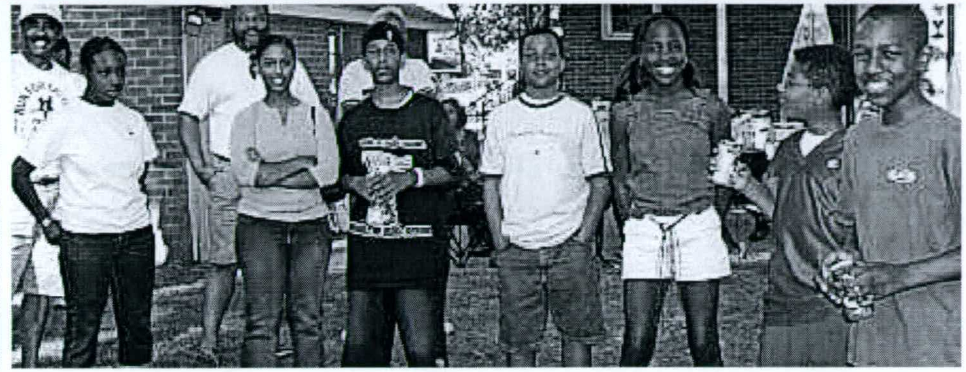
In the 14th century Timbuktu became an important focal point of the gold-salt trade. With the influx of North African merchants came the settlement of Muslim scholars. It made very little difference that the Tuareg regained control of the city in 1433 where they ruled from the desert. Even though they periodically plundered the city, trade and learning continued to flourish.

In 1468 Timbuktu was conquered by Sonni 'Ali, the Songhai ruler. He was generally ill-disposed to the city's Muslim scholars, but his successor, the first ruler of the new Askia dynasty, Muhammad I Askia of Songhai (reigned 1493–1528), reversed the policy and used the scholarly elite as both his legal and moral counsellors. During the Askia period (1493–1591) the city of Timbuktu was at the height of its commercial and intellectual development. Merchants from Wadan, Tuwat, Ghudamis, Augila, and other cities of Morocco gathered there to buy gold and slaves in exchange for the Saharan salt of Taghaza and for North African cloth and horses. The city's scholars, many of whom had studied in either Mecca or Egypt, attracted students from a wide area.

The city declined after it was captured by Morocco in 1591. Two years later, the city's scholars were arrested on suspicion of disaffection; while some were killed during the struggle, others were exiled to Morocco. The small Moroccan garrisons could not protect the Niger Bend, and Timbuktu was repeatedly attacked and conquered by the Bambara, Fulani, and Tuareg until 1893, when the French captured the city. The French partly restored the city from the desolate condition in which they found it, but no railway or tarmac road ever reached it. In 1960 it became part of the newly independent Republic of Mali.

Congratulations to the

TIMBUKTU ACADEMY SCIENCE BOWL TEAMS
National Champions '03, '04 and '05



MATTER - ENERGY FUNDAMENTAL TIMBUKTU ACADEMY 1990 INTERACTION(S) SPACE-TIME

Since 2003, Southern University Timbuktu Academy's Science Bowl Teams have been winners at the National Organization for the Professional Advancement of Black Chemists and Chemical Engineers (NOBCChE) National Science Bowl Competitions. The competition is designed to recognize, encourage and reward scientific knowledge and achievement by students and to encourage scientific study. The Timbuktu Academy is a nationally renowned pre-college and undergraduate mentoring program at Southern University. Led by Dr. Diola Bagayoko, professor of physics, the Academy has been awarded the 1996 and 2002 U.S. Presidential Awards for Excellence in Science, Mathematics, and Engineering Mentoring. Dr. Bagayoko credits the hard work of the scholars, their coaches, parents, and teachers for this success. In its quest for excellence, the Timbuktu Academy is funded by the US Department of Navy, Office of Naval Research, the National Science Foundation, NASA, and the ExxonMobil Foundation. The Academy enjoys the substantial support of the Honorable Mary Landrieu, US Senator, and her staff.

Congratulations Timbuktu Academy Pre-College Scholars

Class of '04

JESSICA CARTER - Baton Rouge Magnet High, National Achievement, Cheerleader, currently attending Georgia Tech

LEISA LAWSON - Baton Rouge Magnet High, National Achievement, Class President, Captain of Soccer Team, currently attending Rice University

KORY PATTY - University High, National Achievement, All District in soccer, tennis and football, currently attending Tulsa University

CACEY STEVENS - Baton Rouge Magnet High, National Achievement, French Scholarship to Belgium, Track, currently attending Southern University

BRITTANI WARE - Baton Rouge Magnet High, President of Mayor's Youth Advisory Committee, currently attending Southern University

YONAS YEMANE - Baton Rouge Magnet High, National Merit, National DOE competition- 3rd Place, currently attending Harvard University

National NOBCChE Science Bowl Competitions

Junior Division = 7th - 9th grades Senior Division = 10th - 12th grades

April 17-19, 2003
Indianapolis, Indiana

National NOBCChE Science Bowl Competition
First Place - Senior Division
Yonas Yemane, Baton Rouge Magnet High
Leisa Lawson, Baton Rouge Magnet High
Brittani Ware, Baton Rouge Magnet High
Nicholas Crawley-Brown, University High

Third Place - Senior Division:
Jessica Carter, Mckinley High
Jason Paul, Baton Rouge Magnet High
William Bagayoko, Mckinley High
Korey Patty, University High
Brittany Matthews, Redemptorist High
(Ms. Matthews Is With La Leadership Institute)

Third Place - Junior Division:
Jerome Meyinsse, Mckinley High
Joshua Berhane, Mckinley High
Kahlia Gager, Mckinley High
Sarai Stansberry, St. Joseph's Academy
Jillian Crawley-Foster, University High

April 12-17, 2004
San Diego, California

National NOBCChE Science Bowl Competition
First Place Winners - Senior Division
Yonas T. Yemane, Baton Rouge Magnet High
Leisa Lawson, Baton Rouge Magnet High
Brittani Ware , Baton Rouge Magnet High
Nicholas Crawley-Brown , University High

National NOBCChE Science Bowl Competition
Third Place Winners
Aaron Gebrelul, Baton Rouge Magnet High
Kristoff Gager, Mckinley High
Ashley White, St.Joseph's Academy
Jillian Crawley-Foster, University High
Justin Paul, Baton Rouge Magnet High

First Place National NOBCChE Science Fair, Junior Division
Aaron Gebrelul, Baton Rouge Magnet High

Coaches:
LaDeta Crawley and George Ware, ExxonMobil;
Cathy Duncan, Community Coffee;
Alberta Lawson, LSU System;
Rachael Carriere and Ella Kelley, Ph.D., Southern University

March 20- 25, 2005
Orlando, Florida

National NOBCChE Science Bowl Competition
First Place - Junior Division
Spencer Carter, Glasgow Middle
Tayla Duncan, University High
Devin Guillory, Glascow Middle
Miracle Johnson, University High
Justin Jefferson, University High

Second Place - Junior Division
Jillian Crawley-Foster, University High
Kristoff Gager, Mckinley High
Justin Paul, Baton Rouge Magnet High
Austin Winslow, University High
Ashley White, St. Joseph's Academy

Second Place - Senior Division
Patrick Carriere, Baton Rouge Magnet High
Vincent Carter, Mckinley High
Chris Ware, Baton Rouge Magnet High
Terrence Woods, Mckinley High

Third Place - Senior Division
Nicholas Brown, University High
Aaron Gebrelul, Baton Rouge Magnet High
Naomi Gebrelul, Baton Rouge Magnet High
Silmon Gebreyessus, Baton Rouge Magnet High
Leah Machen, Baton Rouge Magnet High

Wednesday, August 03, 2005

Back to Index *Published on 03/15/03*

Timbuktu Academy chosen for math award

Capitol news bureau

The White House announced Friday that Southern University's Timbuktu Academy has been selected for the 2002 Presidential Awards for Excellence in Mathematics, Science and Engineering Mentoring, according a Southern University press release.

In all, 10 individuals and six institutions are slated to be recognized for their mentoring efforts by President George W. Bush in a ceremony Tuesday in Washington, D.C.

The Southern University Timbuktu Academy has directly mentored 805 pre-college students and has helped 106 minority college students obtain bachelor's degrees in science.

Another 68 Timbuktu Academy members have either earned or are presently pursuing graduate degrees.

The president annually recognizes the people and institutions that have provided broad opportunities for participation by women, minorities and disabled persons in science, mathematics and engineering at the elementary, secondary, undergraduate and graduate education levels.

Each award includes a $10,000 grant to provide for continued mentoring work.

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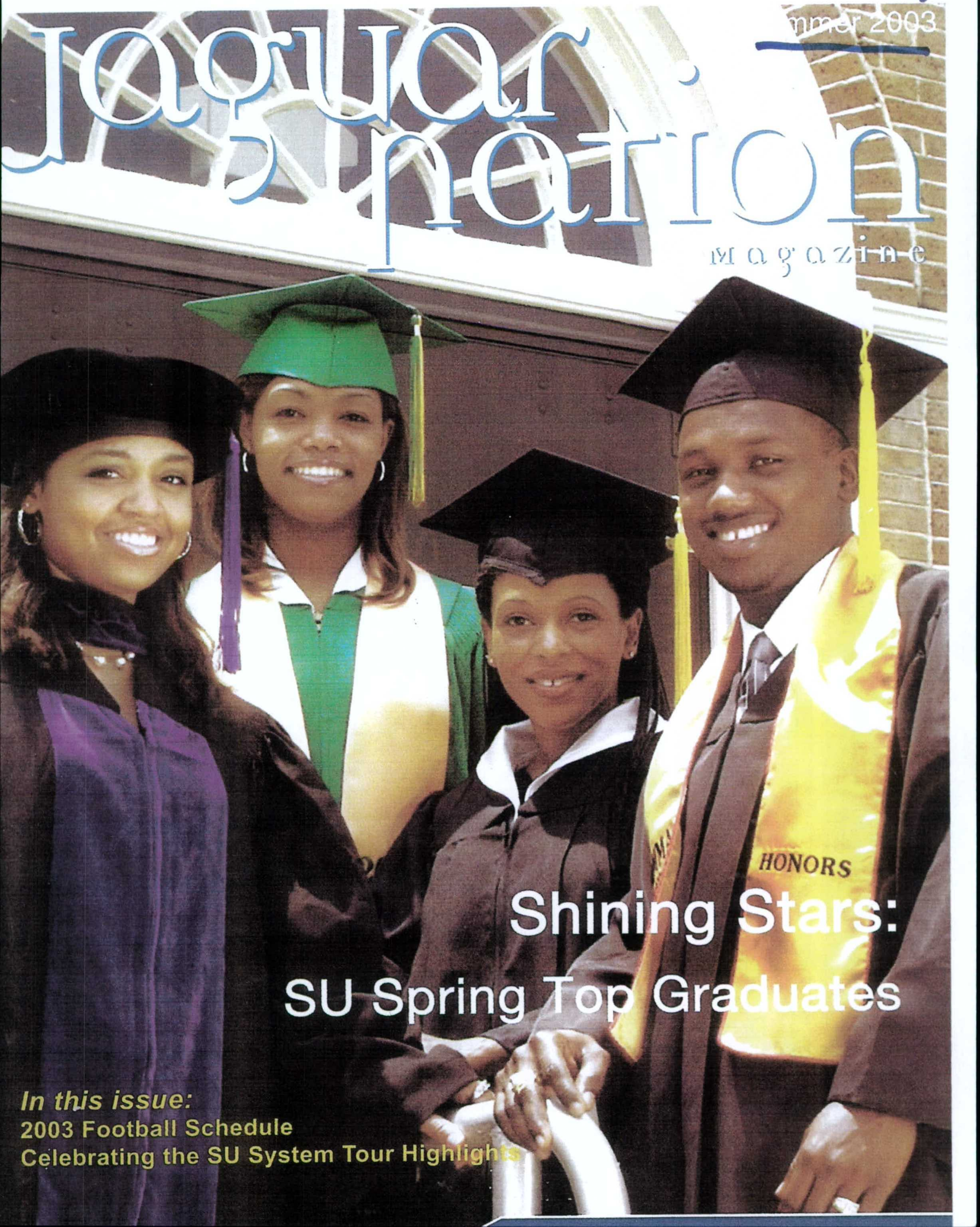


Shining Stars:

SU Spring Top Graduates

In this issue:

2003 Football Schedule

Celebrating the SU System Tour Highlights

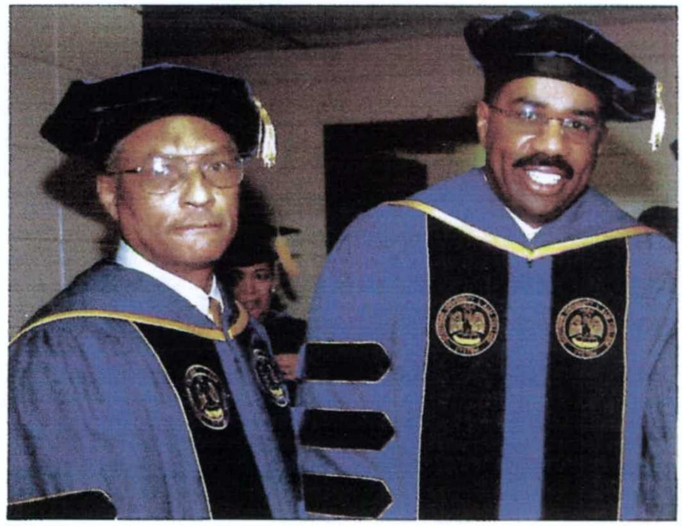
ENTERTAINER STEVE HARVEY ESTABLISHES BOOK AWARD PROGRAM AT SOUTHERN UNIVERSITY - *MAKES $40,000 DONATION*

Entertainer Steve Harvey and his wife, Mary, have contributed $40,000 to ablish a book award program at Southern University, Baton Rouge. The rveys' have also pledged to donate at least $20,000 annually to support eir program at the University.

The Steve and Mary Harvey Book Award Program will assist needy and ademically deserving freshman students with the purchase of college text-oks. Students awarded a Harvey Book Scholarship can receive up to $400 r semester. Awards will be administered by the Southern University holarship Committee.

"We are so grateful and elated about the Harveys' contribution and com-tment to Southern University," said SUBR Chancellor Edward Jackson. The program is desperately needed because most of our students rely on ancial assistance to cover some or all of their educational needs; yet, there no existing program at the University that covers just the cost of books." ckson said that the Harveys' program would help to fill that gap.

Steve Harvey is best known for his starring role in the television comedy, *e Steve Harvey Show*. Moviegoers remember Harvey's performance in *The riginal Kings of Comedy*, a comedy tour made into a documentary by film-aker Spike Lee. He is also the host of The Steve Harvey Morning Show, ndicated in Dallas and Houston. ■



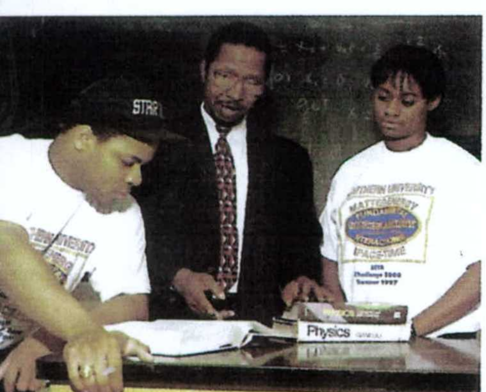
In 2001, Steve Harvey delivered the keynote address at Southern University's spring commencement and was awarded an honorary doctorate degree.

OUTHERN UNIVERSITY RECEIVES PRESIDENTIAL AWARD FOR MENTORING

Southern University's Timbuktu Academy is again among the individuals d institutions to receive Presidential Awards for Excellence in athematics, Science, and Engineering Mentoring. President George Bush cently honored the Timbuktu Academy during a ceremony in Washington, .C.

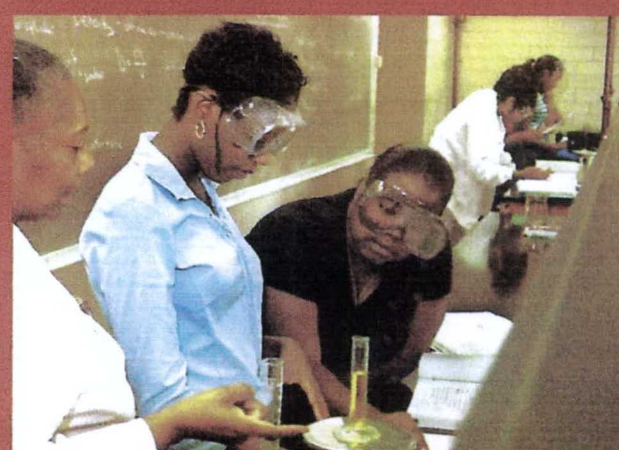
The president annually recognizes the people and institutions that have ovided broad opportunities for participation by women, minorities, and sabled persons in science, mathematics, and engineering at the elementary, condary, undergraduate, and graduate education levels. No more than 10 rsons and 10 institutions are selected each year for recognition. Each ard includes a $10,000 grant to provide for continued mentoring work.

The Southern University Timbuktu Academy provides an education con-uum that spans from elementary school to college that has resulted in 106 minority undergraduate academy students earning baccalaureates of science, 68 academy members having earned or presently pursuing graduate degrees, the direct mentoring of 805 pre-college students, and outreach to more than 5,000 students, counselors, students, teachers, and parents. SU Professor Diola Bagayoko is the program's director. ■



mbuktu Academy students with director Diola agayoko (center). The program recently received e Presidential Award for Excellence in athematics, Science, and Engineering Mentoring.

SOUTHERN UNIVERSITY AWARDED $575,164 GRANT



The SUBR chemistry department has received a $575,164 grant from the National Science Foundation to enhance nuclear magnetic resonance research at the University.

Nuclear magnetic resonance, an important research tool in the life, physical, and environmental sciences, is essential to the study of proteins, polymers, and gels.

The grant provides for the acquisition of a 400-megahertz spectrometer, a valuable instrument that will enhance research experiences for students majoring in chemistry, biology, physics, environmental toxicology, and urban forestry.

Edwin Walker, an assistant professor in the Department of Chemistry, is the grant's principal investigator. ■

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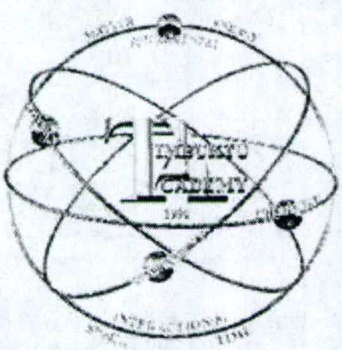
SU Named Among Nation's Leading Institutions for Science, Engineering and Math Mentoring



by Digest News Service
March 21, 2003

Southern University's Timbuktu Academy was recognized by President George Bush as one of 10 individuals and six institutions to receive the 2002 Presidential Award for Excellence in Mathematics, Science and Engineering Mentoring.

The program was recognized at a ceremony in Washington, D.C. on Tuesday.

The President annually recognizes the people and institutions that have provided broad opportunities for participation by women, minorities and disabled persons in science, mathematics and engineering at the elementary, secondary, undergraduate and graduate educational levels.

Each award includes a $10,000 grant to provide for continued mentoring work.

The SU Timbuktu Academy provides an educational continuum that spans from elementary school to college.

The program currently has 106 minority undergraduate academy students earning baccalaureates of science, 68 academy members having earned or presently pursuing graduate degrees, the direct mentoring of 805 pre-college students and outreach to more than 5,000 students, counselors, students, teachers and parents.

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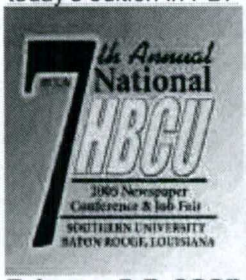

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SU Honors College inducts 99 new members

By Gabrielle Maple
October 26, 2001

Ninety-nine students were inducted into the Southern University Honors College at the 10th annual Honors College Pinning Ceremony held in the Cotillion Ballroom on Thursday October 18,2001.

Over 200 hundred guests, many travelling from locations around the state and as far as California, Texas, and Florida, were in attendance.

"I feel that this event is very much worth coming from Palmetto I'm quite honored to have a son entering the Southern University Honors College", said Rosa Thomas mother of William Thomas one of the freshman inductees.

The Honorable John F.K. Belton, chairman of the Southern University Board of Supervisors delivered the "Honors Charge."

"Parents should be proud of the sacrifices they made to get their children to this stage," said Belton.

Belton, a 1990 graduate of the Southern University Law Center, also discussed the choices we make in our daily lives that bring us forth or push us back. He ended his speech with his five keys to success.

The program began with honor guardsman of the Navy ROTC leading the procession of student into the Cotillion Ballroom Room. The Reverend Jesse B. Bilberry, Pastor of Mount Pilgrim Baptist Church of Baton Rouge and a member of the Southern University Board of Supervisors gave the invocation.

Guest vocalist Diane Pullen, mother of National Black Achiever, Honors College Scholarship recipient, and Timbuktu Academy award recipient Anthony Pullen, stirred the souls of the crowd with her soulful rendition of The Battle Hymn of the Republic.

" I don't know about everyone else, but she brought tears to my eyes", sighed Dean Wade as she stood to give Pullen a standing ovation.

Toni Bowie, president of the Honors Student Association presided over the Induction

Ceremony. Each student was pinned by upperclassmen after formally introducing themselves to the university community.

The "Class Response" was given by members of the Honors College in the form of a short drama, Fifty Stars and Thirteen Stripes. Katia Desrouleaux, narrated the drama.

Other participating freshman were Miesha Beverly, Baton Rouge,; Mariol Charles, Opelousas,; Chalonda Jasper, Hammond,; Arthur Monroe Jr., Baton Rouge; and Carmen Rossum, Greenwood. Upperclassmen Alaysia Delaney, Donaldsonville, and Douglas Touissant, Glynn, provided music for the presentation.

"The program was inspirational, it inspired me to go on and be the best that I can be," said Melissa Edwards, a sophomore nursing major from Baton Rouge.

SU Honors College inducts 99 new members

Post your feedback on this topic here

No feedback has been posted yet. Please post yours!

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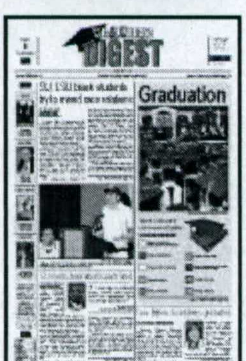

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News

SU Alumna wins Miss Maryland

Mistie Adams, SU graduate in 1999 takes crown
by Gary Holloway
November 30, 2001

Former Southern University student won the crown of Miss Maryland and is scheduled to compete in the Miss USA pageant.

Mistie Adams, chemistry, pre- med graduate in 1999, won the title of Miss Maryland in a competition that included a personality interview, swimsuit competition, evening attire and final speech competition.

While attending SU, Adams was a member of the Beta Psi Chapter of Alpha Kappa Alpha, a member of the Honors College and Timbuktu Academy.

In order to qualify for the Miss Maryland competition, Adams had to go through a series of auditions that included a photo interview. She will next compete in the Miss USA Pageant, which will be televised on CBS in Gary, Indiana.

"It's really didn't think about winning," said Adams. "I just tried to do the best I could."

Adams placed second runner-up in last year's pageant. Currently she is pursuing a career in entertainment, acting and dancing.

Presently she dances for the Joy of Motion Dance Studios, where she specializes in modern jazz and hip-hop dance for the past two years.

SU Alumna wins Miss Maryland

Post your feedback on this topic here

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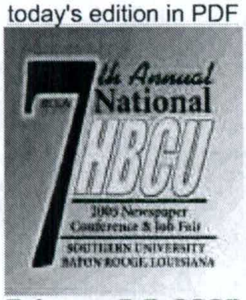

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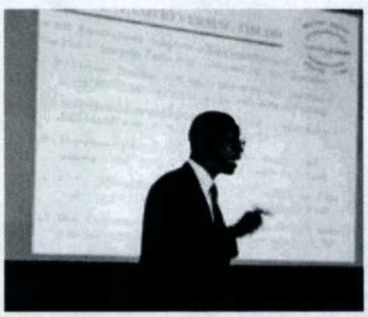
The Southern DIGEST online edition

"Sentinel of an Enlightened Student Body"
Established 1928 - Online Since 1999

The Official Student Newspaper at
Southern University - Baton Rouge, Louisiana

Staff, students attend digital summit



Dr. Diola Bagayoko, director of the Timbuktu Academy speaks on the Digital Divide at a conference

By Ebony Hunter
October 26, 2001

On October 4-5, 2001, 28 Southern University students, along with staff, attended the Historically Black College and Universities (HBCU) Digital Divide Summit Conference.

The conference was presented by Tennessee State University and held at Jackson State University.

The HBCU Digital Divide Summit Conference was sponsored by AOL—Time Warner Cable Foundation. The Title 3 project, The New Models for Teaching, Mentoring , and Learning, directed by Diola Bagayoko, director of the Timbuktu Academy and PIPELINES, provided funding for Southern students to attend.

The theme of the conference was "Accelerating the Closure of the Digital Divide on HBCU Campuses."

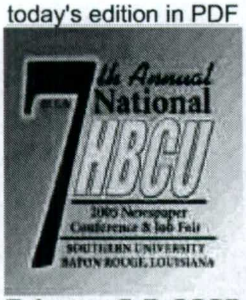
The conference addressed technological issues as it pertains to race, ethnicity, income, education, gender, age, geography, and household composition. The conference offered numerous workshops to provide resolutions for these pertinent questions which were presented to students and faculty alike.

The conference specifically dealt with the gap between HBCU's and other institutions of higher education. Different speakers elaborated on their views of digital divide and presented many resolutions that could help succumb to minimizing the digital gap. Speakers expressed feelings on improving minority access and job opportunities, as well as, creating stronger information technology support systems at historically black colleges and universities.

One keynote speaker elaborated on the importance that students have in closing the digital gap and helping them with the realization of their role.

"We must come to grips with the inescapable fact hat technology infusion within our

today's edition in PDF



February 3-5, 2005
Holiday Inn South

Current Weather Conditions for **Baton Rouge** **71 F** more...

Southern University Homepage

institution is no longer an option, it is an absolute necessity for our survival," stated Dr. James Hefner, President Tennessee State University.

Bagayoka presented at the conference. His presentation focused on the importance of possessing a supportive administrative leadership and systematic mentoring programs in closing the digital gap.

Attendees of the conference felt that it was very successful.

"The conference was well organized and I was impressed with Southern University students participation. They were not shy at all and I think it is a positive outlook. I hope that they would bring the conference to Southern University," stated Karen Simms, conference chaperon, Program Editor and Assistant to Director of Timbuktu Academy.

Digital Divide Summit

Post your feedback on this topic here

11/16/2001	As one of the main developers of this...	Dr. Eugene E. Jones
11/16/2001	The proceedings of the TSU-AOL-Time...	Eugene E. Jones

(Feedback requires a Javascript-compatible browser)

The Southern DIGEST online edition

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Southern University - Baton Rouge, Louisiana

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Timbuktu Academy featured in national career magazine

BY JOSHUA PALMER
April 15, 2005

Timbuktu Academy at Southern University, a mentoring program for undergraduate and graduate science, mathematics and engineering majors, is known for its innovative approach in academics. The program was recently featured in *The Black Collegian*, "the career magazine for students of color."

The article, "The Timbuktu Academy -- The Genius Factory at Southern University," focuses on the achievements and the founder of the Academy.

Timbuktu Academy is led by Dr. Diola Bagayoko, a physics professor at Southern. The Academy began in 1990, and the Office of Navel Research began granting funds for it in 1993.

"The reason the Timbuktu Academy was started was because of three simple reasons," Bagayoko said. "From middle school to grad school I'd had mentors to help me achieve, and in 1984 I begin mentoring students right here at Southern University, and finally because of my wife -- she said that I should put my skill and my brain power to work to help others achieve."

With funding from the Office of Navel Research with over $11 million to date over the past decade, the Timbuktu Academy has helped and mentored nearly 2,000 students.

It has aided in improving standardized test scores as well as developing superior study skills among high school students.

Arthur Monroe, current Southern University Student Government Association president is one of many students who participated in Timbuktu's high school program before attending college.

"I attended the program in high school in 1999 and the program prepared me for college," Monroe said. "Most importantly it exposed me to opportunities at HBCUs. Had I not been exposed I probably would have never came to Southern and gotten involved in the SGA."

Timbuktu has also been a driving force in on-time graduation and high GRE scores for undergraduate students and full financial support in graduate students pursuing a Ph. D. The Academy also allows students research opportunities with NASA.

"The Academy has nurtured my love for research and I now plan to pursue my Ph. D. in chemistry at Purdue University," said Aliah Dugas, a senior from Lafayette.

A similar program sponsored and directed by the Academy that was also mentioned in the article is the Louisiana Alliance for Minority Participation, better known as LAMP.

Candace Semien, the director of outreach operations at LAMP, said, "LAMP is designed to replicate the Timbuktu Academy at eleven universities state wide across Louisiana and this feature in the magazine has given the academy a national spot light."

Bagayoko agreed that the article has served the Academy and its mission well.

"(The article served as) a tremendous good service by making it known to community as well as the nation -- I even got a call from Europe."

Timbuktu Academy featured in national career magazine

Post your feedback on this topic here

No feedback has been posted yet. Please post yours!

(Feedback requires a Javascript-compatible browser)

ILLUSTRATIVE PICTURES
of a few activities at the
Timbuktu Academy

An Attachment to the Final Report to the Department of the Navy, Office of Naval Research (ONR), for Grant No. N00014-98-1-0748

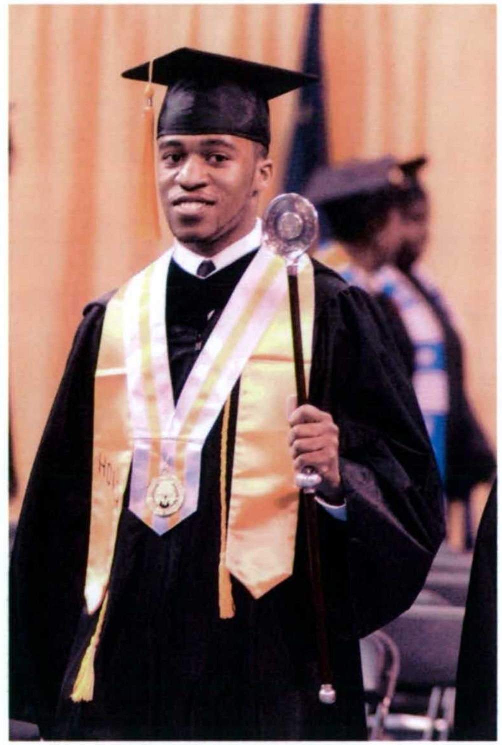

GLOBAL REACH
UNIVERSAL EXCELLENCE

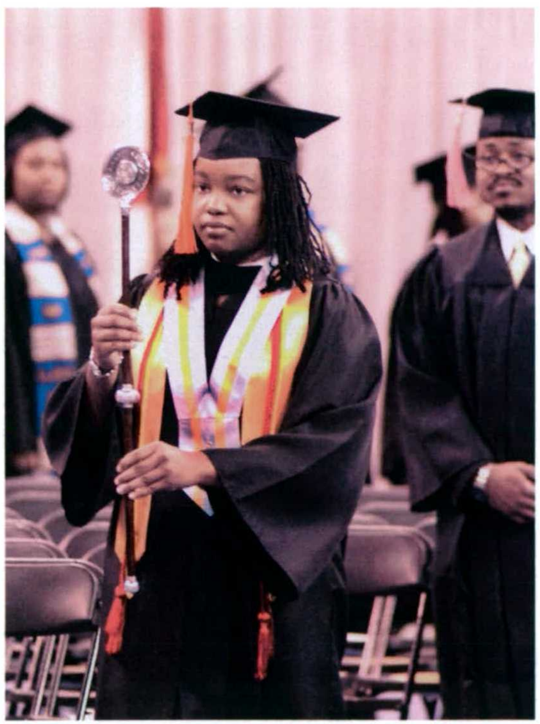
Timbuktu Academy Student at the Digital Divide Conference in Jackson, Mississippi, 2001

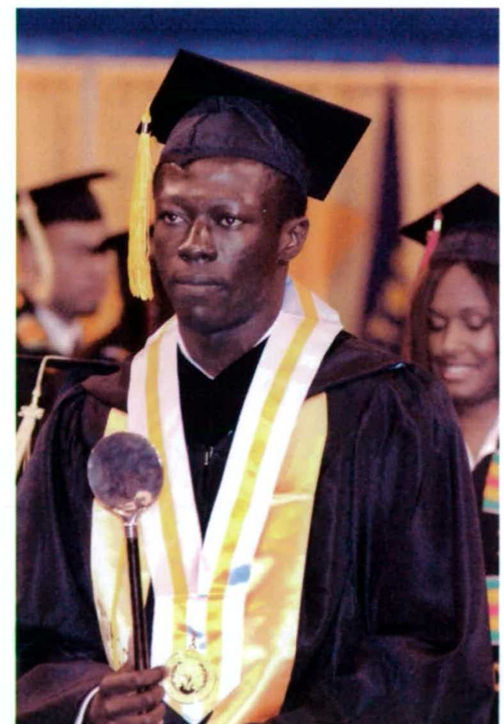
Teacher Participants: Educational Reform Workshop
Southern University and A&M College- Baton Rouge
2000

Timbuktu Academy Scholars
Student Grand Marshals

Kimberly Wright 2003, Anthony Pullen 2004, Divine Kumah 2004, Michael Ashenafi 2002(not shown)



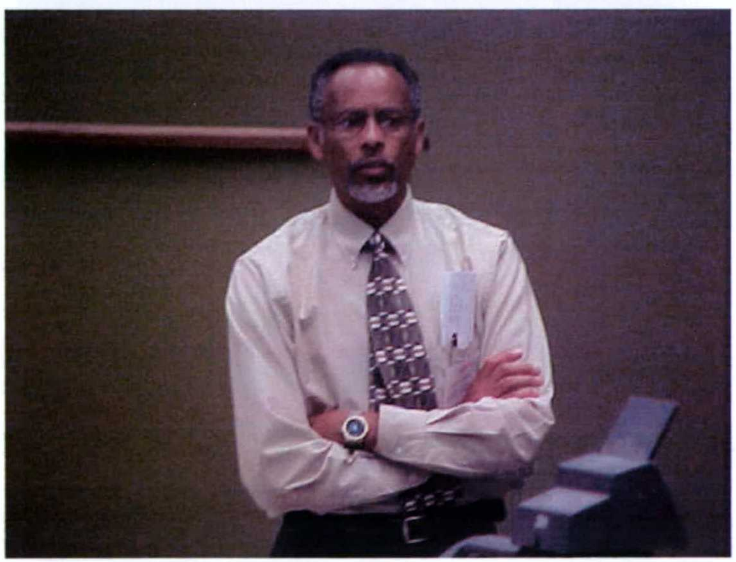




Guest Speaker
Rear Admiral Williams, Jr., Addresses Scholars of the Timbuktu Academy - 2004

Guest Speaker
Rear Admiral Williams, Jr., and Scholars of the Timbuktu Academy
2004

Careers Day-Southern University and A&M College- Baton Rouge, Louisiana. Ms. Helen Hill and Colleagues from Lawrence Livermore National Laboratory Address Scholars of the Timbuktu Academy 2002



Careers Day
Southern University and A&M College- Baton Rouge
2002

Guest Speaker Addresses Scholars of the Timbuktu Academy
Captain J. Sapp, Commander, NROTC, SUBR-Baton Rouge
Summer 2004

Bagayoko with students in a class at Egan Elementary School after his presentation on *"The Scientific Method for All,"* January 3, 2004

Scenes of NAFEO High Tech Student Expo
Washington Hilton Hotel-March 21, 2002
Dr. Humphry, NAFEO, and Dr. Orlando Taylor, Howard Univ., Address Student Researchers

Scenes of NAFEO High Tech Student Expo
Washington Hilton Hotel-March 21, 2002
First Place Winners of the Technical Presentation Competition
The first places prizes (desktop computers) were donated by Gateway

Scenes of NAFEO High Tech Student Expo
Washington Hilton Hotel-March 21, 2002
Second Place Winners of the Technical Presentation Competition

Bagayoko and Fazely (Back Row, Left to Right) with Timbuktu Academy Seminar Speakers from Lawrence Berkeley Laboratory, California (UC Berkeley)-2003

Toi Burton (left) and a colleague from the Army: Both were pre-college scholars of the Timbuktu Academy; Mr. Burton just successfully completed the Naval Preparatory Academy in the Spring of 2005.

Timbuktu Academy Opening Ceremony

2001 – **Reaching out to pre-college students and their parents**

Timbuktu Academy Closing Ceremony

2001 – **Reaching out to pre-college students and their parents**

National Merit (NM) and National Achievement Scholars

The Timbuktu Academy contributed quantifiably to the scholastic preparation of these pre-college scholars and of others

Sarai Arnold (NM)

Azaria Azene

Kelley Bagayoko

Namory Bagayoko

Jasmyn Dyer

Darrell Ford (NM)

Jonathan Grey

Sarne Hutcherson

Chi-Chi Ibekwe (NM)

Lucy Lomas

Shanna Magee

Marques McCormick

Jason Mellad (NM)

Ashaki Olinga

Kimberly Osagie

Brandis M. Rawls

Eme Udoh

Derrick Wells

Tyson Wickboldt

Keisha Williams

Ruth Yemane (NM)

Julia Young

Magnet Mania

Students and teachers from Forest Heights Elementary explain the GLOBE Program to potential magnet students and parents.
11/20/01

FHES Parental Involvement

Dr. Diola Bagayoko, PIPELINES Program Director, addresses Forest Heights Elementary School Parents -- 3/7/02

FHES Parental Involvement Meeting (cont'd)

Over 200 parents and students attended the meeting!
3/7/02

View of Timbuktu Academy undergraduate seminar
Summer 2004

Timbuktu Academy Opening Ceremony-Summer 2004

Reaching out to pre-college students and their parents

Timbuktu Academy Opening Ceremony-Summer 2004

Reaching out to pre-college students and their parents

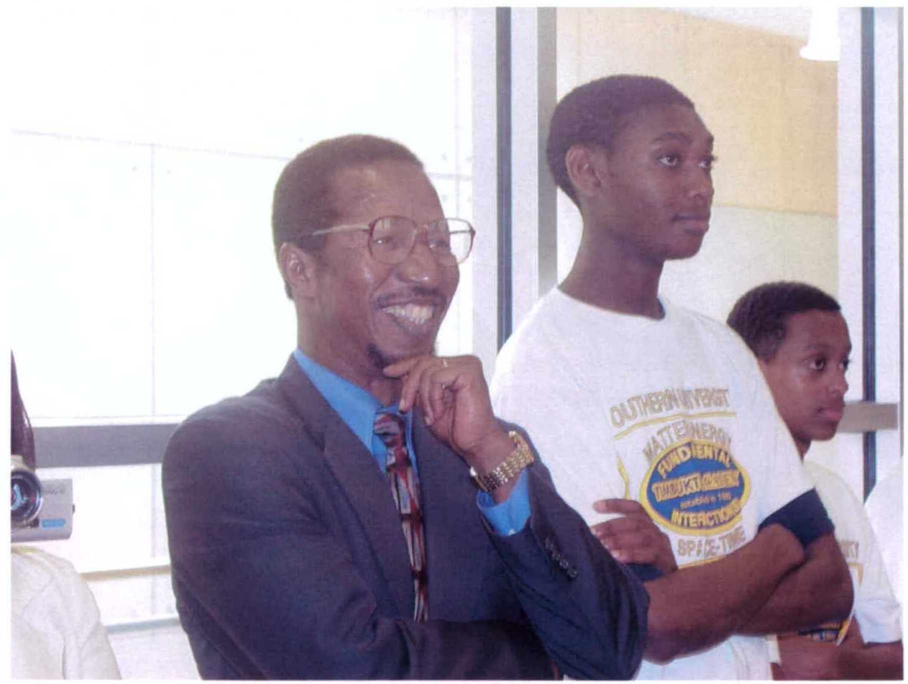
Scholars (Elementary School Students) of Getting Smarter at the Timbuktu Academy (GeSTA)-Summer Program 2004

Timbuktu Academy U.S. Presidential Award Ceremony 2003
Dr. Bagayoko, Dr. Petonito, Dr. Ford, and Dr. Murberger
(From left to right)

Rear Admiral Ann Rondeau (Below) and staff address pre-college scholars of the Timbuktu Academy-Baton Rouge, Louisiana
July 2004

Rear Admiral Ann Rondeau and staff address pre-college scholars of the Timbuktu Academy-Baton Rouge, Louisiana July 2004

Rear Admiral Ann Rondeau and staff address pre-college scholars of the Timbuktu Academy-Baton Rouge, Louisiana
July 2004



Rear Admiral Ann Rondeau and staff address pre-college scholars of the Timbuktu Academy-Baton Rouge, Louisiana, July 2004
Also shown below are Mr. Godfrey and Mr. Smith, the hosts.

Rear Admiral Ann Rondeau and staff address pre-college scholars of the Timbuktu Academy-Baton Rouge, Louisiana
July 2004

LIST OF ACTIVITIES BEARING ON MENTORING
Systemic Mentoring at the Timbuktu Academy
(The formula for student retention, on-time graduation, quality enhancement, the development of professionalism, and the gateway to graduate school and to competitiveness)

As explained in the literature (Education, Vol. 115, No. 1, pp. 31-39, 1994), systemic mentoring is the **coupling** between *quality teaching and quality learning* on one hand, and between *quality teaching and quality research* on the other. Student retention, on-time graduation, and attendance and success in graduate school, according to the integrated law of human performance, are not "magical events." They are natural consequences of exposure to the proper content and skill, in the proper sequence, at the adequate scope and depth, in a fashion that guarantees adequate practice—including research participation, as shown in the aforementioned article. Consequently, systemic mentoring, woven into the instructional, research, and service fabric of departments and units, is the hallmark of the Timbuktu Academy (http://www.phys.subr.edu/timbuktu.htm). We summarize below the ten (10) commandments of the *systemic mentoring model of the Timbuktu Academy,* as per its brochure that is available at the noted web site. **These activities are keyed to the paradigm of the Timbuktu Academy.**

1. **Financial support** is provided to the scholars from *a variety of sources* – guidance, monitoring, and other components of systemic mentoring that guarantee the use of the resulting "time dividend" for studies, research, and related enrichment activities on a full time basis. Continued support from the Academy, for a scholar, requires full time "studying and research" during the academic year. The diversified funding base for the scholars include the TOPS, the Federal Student Financial Aid, limited support from LS-LAMP and other scholarship and fellowship sources, including unit and institutional funds.
2. **Communication skill enhancement** - A host of listening, speaking, reading, writing and related activities are aimed at developing the mastery of the applicable language (English), a vehicle of thought. This activity entails vigorous exposure to technical communication as provided for in *"Writing for Success"* (1998, McGraw-Hill Companies, pp. 135-176 and pp. 212-215).
3. **Comprehensive, Scientific Advisement** - The proper sequencing of courses is treated with the utmost care. Indeed, the internal rigidity (or taxonomic structure) of science, engineering, mathematics, and technology (SMET) disciplines requires this approach. Empowering the learner is a central aim of mentoring. This empowerment includes grasping the power law of performance [(T=A+B(N+E) -P)] and its extension, the integrated law of human performance (ILP); understanding and applying cognitive condensation for meta-and mastery-learning; and knowing a few time-tested quotes like the Jaime Escalante Equation, its corollary, and others. The Uri Treisman discovery in calculus, at Berkeley, is an indirect support of the power law of performance (the degree of alertness and of practice is expected to be higher in a group or cooperative learning environment). PORTFOLIO PER STUDENTS; MANDATORY MEETING FOR ADVISEMENT
4. **Tutoring** - Tutoring by faculty members and particularly by peers will continue to be available to the students or scholars who need it. (In fact, regular tutoring areas are often taken over by self-organized study groups!) Tutoring is for excellence, not for remediation; it is

to address holes in a background and to reinforce known essentials; it is not a sign of any lack of intrinsic smartness, so says the power law of human performance, but rather a wise recognition of the internal rigidity of SMET fields. Incidentally, tutoring by scholars also promotes their communications skills and sense of self-worth while they review materials (so says the ILP)!

.5. **Generic research activities** - Rigorous literature searches are conducted by the scholars on several subjects. They master sophisticated search algorithms, electronic searches, and related iterations. The scientific literature is an unlimited source of research questions! Refereed literature is the standard for SMET disciplines. Current awareness readings are part of these generic research activities—to follow developments as they occur. So is the development of communication (WRITING) skills germane to research. (Semester Reports, Summer Reports, and Report on Special Lectures or Seminar Sessions)

6. **Specific research project execution** by the scholars of the Timbuktu Academy, Faculty members and researchers at Federal and industrial laboratories serve as research supervisors and mentors to scholars, year round. According to the integrated law of human performance, research experiences should prepare for graduate studies and for productive research careers. Seeking summer research opportunities on-line, at conferences, and through visits to various laboratories and agencies is one requirement for a mentoring program. Assisting scholars to apply vigorously and professionally for these opportunities and maintaining adequate files on each scholar, partly for the purpose of writing substantial (as opposed to general and vague) recommendations are some tasks for mentors to accomplish. Please see the section on achievements for details the research participation of the scholars.

7. **Development of a professional culture** - Every scholar is exposed to discussions that explore the dimensions of *ethics in science*. Immersion in a professional culture demands a regular reading of technical journals and appropriate magazines of professional societies, conference attendance, and collaboration with others. Current awareness needs no explanation in an era of information explosion. Professional practices and standards are set and seen in publications, *seminars*, and at conferences. As for the need for and value of collaboration, we simply assert that not one individual has built or operated a nuclear submarine, an aircraft carrier, or a space shuttle alone!

The **Weekly Seminar** plays a crucial role in the development of a professional culture. It repeatedly emphasizes the need for superior academic performance and provides a clear road map for any student to make a genius out of himself. Topics that are discussed in a variety of different ways include *"The Integrated Law of Human Performance"*, *"How to Study Successfully"*, *"Problem-solving Proficiency by Design"*, *the scientific method in practice, ethics,* and the quintessential importance of communication skills. At the weekly seminars, the presentations are made by eminent guest speakers, faculty, and Timbuktu Academy scholars.

In addition to the seminars, the Academy scholars are required to attend and make research presentations at **local, state and national conferences (Statistics)**. The Timbuktu Academy also conducts summer bridge programs for pre-college students. Every summer the **Summer Pre-College Quiz Bowl** is the culmination of these programs. Its importance resides in the *celebration of academic excellence*, intellectual prowess and the promotion of scholarship as an integral part of the professional value system.

8. **Development or Enhancement of Communication, Computer, and Technological Skills** - The mastery of productivity tools, including word-processing, spreadsheets, database, graphics, other applications, and scientific programming (C++, FORTRAN, etc.) are needed. Advanced exposure has to include a programming language. (The

need for these activities is given by the environments to which the students are destined, i.e., graduate schools and the global market). Given the primacy of languages as vehicles of thought (i.e., paradigm of the Timbuktu Academy), efforts are devoted, *year-around*, to the development or enhancement of communication skills (including technical writing).

9. Monitoring - With monitoring, throughout the semester, potential problems are avoided before they become permanent Fs. Preventive measures include concentrated efforts, extra-tutoring, and the last resort, dropping a course. The former two steps are best when they are taken as early as possible. The latter step is not an available option past a certain date after mid-term! The monitoring of research participation and performance is critical for another reason: *the development or reinforcement of non-cognitive skills that undergird success (self-discipline, hard work, assiduity, working well with others, etc.).* Monitoring and evaluation are part of a professional environment, without them, who will know what a beautiful job a scholar has done! (Reference the Portfolio)

10. Guidance to Graduate School - **It begins in the freshman year** (or earlier) and includes research experiences, conference attendance, *GRE preparation* starting the freshman year, and opportunities for financial support for graduate studies. Placement in graduate programs follows steps similar to those for summer placement. The number and the extent of the opportunities depend on the cumulative grade point average for the BS degree, the courses taken, research experiences and results, and the GRE score. These measures of preparedness for graduate studies are also indicators of self-discipline, focus, the quality and scope of exposure to subject content, and research skills. They are, hence, indicators of the likelihood that a prospective graduate student will pass the required courses and will make contributions in research! In addition, graduate preparation will include an understanding of the non-academic factors that are critical to success in graduate school. Emphasis will be placed on the establishment of a seamless transition to graduate school.

The rigorous reasons for the above detailed description of the components and activities of our systemic mentoring are implicitly in the Section above on our understanding of the issues. The continued implementation, expansion, and institutionalization of these activities, as they apply to minority students and others, are core activities of the Timbuktu Academy. *We should add the formal institutionalization of systemic mentoring in SMET departments (1997) and all departments (1998) at SUBR.*

It is important to note that these steps address all four (4) key transition or articulation points. The latter are high school to college SMET, college undecided to college SMET, community colleges to four-year college SMET and college SMET to graduate and Ph.D. programs in SMET. The working rationale that partly explains the success of the above model includes the fact that transition activities not coupled with systemic mentoring (structured organization) do not have lasting effects.

The above steps for systemic mentoring are rigorously applied from middle school to Graduate school, with obvious adjustments for the middle school. They are followed to the letter, as noted above, for undergraduates and graduate students. For high school students, instead of preparing for the GRE, we prepare for the ACT/SAT. We guide in the course taking needed for successful enrollment in Science, Mathematics, Engineering, and Technology (SMET) disciplines. The various subprograms where the above activities are carried out include:

MATTER - ENERGY
FUNDAMENTAL
TIMBUKTUACADEMY
1990
INTERACTION(S)
SPACE - TIME

Deciphering the Process of Competitive Education: First 5 of the 10 Strands

(1) *The law of performance says that all students can learn--at a competitive level. It is the scientific basis for high expectations for all students!* It also says that exposure to competitive curricula, over the years, and adequate learning and practice are <u>necessary</u> for high academic achievements by most students. IT BEGINS WITH EXPECTATIONS.

(2) The law of performance does not suggest that adequate attention is not to be paid to the physical, emotional, and mental health of the learner. Physiology, neuroscience, etc., dictate adequate attention to physical, emotional, and mental health.Basic care, including vaccinations, hygiene, and a comprehensive vision test (the latter for reading issues) are necessary.

(3) There is no substitute for standard-based subject matter and skills contents of each and every course, from pre-K to graduate school and beyond.

(4) There is no substitute for the adequacy of the battery of courses taken at every grade level. A national, reference curriculum, from K through college, will inform parents and students of prevailing competitive norms or standards.

(5) There is no way to circumvent the *internal rigidity* (i.e., sequential nature of aspects of knowledge). Consequently, the knowledge and skills base of the learner has a great influence on the "acquired ability" to learn. Particular difficulties in many courses are often due to utterly inadequate background as opposed to a lack of "smartness." Writing follows reading. Calculus follows arithmetic, algebra, and basic geometry and trigonometry. *Reading is the foundation of formal learning*.

Deciphering the Process of Competitive Education: Last 5 of the 10 Strands

MATTER - ENERGY
FUNDAMENTAL
TIMBUKTUACADEMY
1990
INTERACTION(S)
SPACE - TIME

(6) There is no substitute for the devotion of "adequate" time to learning tasks! So says the law of performance (LP). "Adequate" is to be determined using competitiveness criteria and national norms and standards. In the absence of a reference curriculum, those with the least intellectual, material, and financial means are likely to have the most difficulty in the determination of a competitive curriculum and of the "adequacy" of the time on learning tasks. This holds for parents, teachers, and students.

(7) There is no substitute for quality teaching, with its inherently closed feedback loop. Such a teaching commands a significant portion of the out-of-class time through graded assignments. These assignments simulate the actual way in which knowledge is applied and research is conducted. They do so better than any test, however comprehensive it may be. Further, they mold study habits over time; these habits are critical aspects of the unwritten curriculum.

(8) There is no substitute for parents or guardians in ensuring that adequate time is spent on learning tasks during the academic year and in the summer (i.e., reading and report writing). Consequently, they have to limit TV viewing, video playing, and listening to music. These activities and similar ones are privileges that should be earned by young students after doing school work.

(9) There is no substitute for familiarity with the format and subject/skill content of applicable tests. This tautology applies to all standardized tests, whether they are norm- or criterion-referenced, from K through the Ph.D. degree.

10. There is no substitute for efforts and practice in acquiring and enhancing proficiency in a complex process, from reading to writing, research, and problem-solving, sports, and the arts. So says the law of performance, regardless of claims of "innate" abilities.

Appeared in the Journal of Urban Education, Vol. 2, 2005 (ISSN 1546-3206), Pages 42-56.

A Significant Other for Effective Education
Making Adequate Time for Teaching and Learning

ABSTRACT

Our review of current education reforms, of the results of the Third International Mathematics and Science Study (TIMSS), and of some teaching and learning models straightforwardly leads to a significant other for effective education, i.e., the adequacy of the time on learning tasks. The plethora of topics in middle and high school science and mathematics constitutes a roadblock to this adequacy of the time on learning tasks both in teacher training and professional development and in K-12 education. Our analysis leads to the necessity for the structured or cognitive condensation of the curriculum and of lessons, i.e., the implementation of "less is more." In particular, this proposed solution seems to be necessary for closing academic achievement gaps in urban education.

Introduction: A Review of Relevant Issues

The Educational Reforms

Following the wake-up call by "A Nation at Risk" in 1983, several professional societies, state, and federal educational agencies launched various educational reforms that are somewhat synthesized in the National Science Education Standards [National Research Council (NRC)l, 1996]. Project 2061, or Science for All Americans, of the American Association for the Advancement of Science (AAAS) and the first Standards of the National Council of Teachers of Mathematics (NCTM) both appeared in 1989. They were followed by Scope, Sequence, and Coordination (SS&C) of the National Science Teachers Association (NSTA) in 1990. America 2000 and its predecessor, Goals 2000, set ambitious expectations for American K-12 education. A critical role was played by the National Governors Association (NGA) in keeping education at the top of the national agenda. The Benchmarks for Sciences [AAAS, 1993] delved into the curriculum themes and strands that are judged necessary for the implementation of "less is more" which we renamed "More in less."

Unlike the first standards that were published in the late 1980's and that focused on content, teaching, and assessment standards, i.e., factors within the control or reach of teachers, the National Science Education Standards (NSES) [NRC, 1996] added a broader context by setting standards for professional development, science programs, and educational systems. A summary of some essentials in the noted reform blueprints can be found in NCTM Standards and in NSES. A few general points pertaining to the curriculum and to teaching follow.

All students can learn. This belief has been expressed by all the blueprints. It underlines the need for high expectations for all students. Unfortunately, none of the reform blueprints, to date, provided the known evidence [Snoddy, 1926; Newel and Rosenbloom, 1981; Bagayoko and Kelley, 1994] that all students can learn. The reforms value the *process of learning* and of doing science, mathematics, and engineering as much as the subject content. Hence, meaningfully engaging students in the learning process (i.e., hands-on, mind-on) is paramount. Further, such an active involvement of the learner promotes "thinking and problem-solving proficiency." The *thematic and strand approach* to curricula and to teaching is highly recommended. Emphasis is to be placed on major concepts, principles, and laws. The understanding or grasp of key content areas is to be achieved through "active learning," including group and *collaborative learning*. The importance of the thematic and strand approach resides in its ubiquitous impact on (a) teacher training, (b) teaching, and (c) learning. Essentially, a plethora of disjointed topics in a curriculum is a roadblock to effective teacher preparation and in-service. Further, it is a major factor in reducing teaching to providing a multitude of unrelated facts to memorize. Consequently, it naturally induces a tendency to memorize, on the part of students.

The sequencing of various topics in the curriculum (in a given course and from a given grade level to another) is recognized to be very important. It directly follows the *"sequential rigidity"* described above. The importance of proper sequencing is reflected in the name of Scope, Sequence, and Coordination (SS&C). The major cycles of child development, from sensory-motor and concrete operational to formal, operational stages partly dictate sequencing—in addition to the internal structure of disciplines of knowledge. SS&C called for the elimination of the *layer-cake approach*. In the US, this approach dictates biology in the 9th grade, chemistry in the 10th grade, and physics possibly in the 11th to 12th grades. In fact, the coordination feature in SS&C also supports the elimination of the layer-cake that was established in 1898 by the National Education Association (NEA). So does the true *interdisciplinary approach* to science teaching, particularly at the pre-college level. Further, and even though it is not discussed by the reform blueprints, the inescapable preponderance of physics phenomena and laws in everyday life should suffice to justify a speedy elimination of the layer-cake approach. *The relevance and the contemporary nature* of the subject content and skills in reformed curricula, teaching, and outcome assessments reflect the fundamental need for motivating the learner, immersing the learner in and preparing him for contemporary practices. Blueprints, from the NCTM Standards to the National Science Education Standards (NSES), underscore this relevance and related integration of *contemporary knowledge, technologies, and practices*. Unfortunately, the referenced integration is too often taken to mean the addition of new subjects or book chapters, as opposed to a restructuring that weaves recent developments into the curricula and teaching practices. This contention is based in part on the growing sizes and weight of textbooks at all levels.

A great merit of NSES consisted in its recognition of the "system approach" or of the gestalt nature of the educational continuum. They address not only the curriculum and teaching, but also evaluation and assessment, professional development, science programs, and educational systems. The critical importance of this contribution of NSES is partly apparent above, in our discussion of the manner in which the curriculum drives teacher preparation, teacher in-service activities, and classroom activities.

Major Findings of TIMSS

Several reports and books discussed the results of the Third International Mathematics and Science Study (TIMSS). In particular, William H. Schmidt et al [1997a, 1997b, 1997c] thoroughly discussed the differences between the K-12 mathematics and science curricula in the US as compared to those in some of the other 52 participating countries, including Japan, Germany, and Singapore. The reader is urged to consult these references for details on the science and mathematics achievements of US students in the international context. In summary, the US fourth, eighth, and 12th graders respectively placed around the top, the middle, and the bottom, respectively, in both science and mathematics. The TIMSS findings that concern us most in this work are not these rankings of the US students, but rather the following four (4) that relate to the curriculum, teaching, and professional development.

- At the middle and high school levels, *the numbers of topics in US mathematics and science curricula are 2 to 3 times* the corresponding numbers in Japanese, European, and other curricula. "Splintered vision," "a mile wide and an inch deep" are some of the expression utilized by Schmidt et al [1997a, 1997b, 1997c] to describe not only the plethora of topics in US curricula, but also the disjointed nature of these topics.

- The classroom time (seat–time) in the US, for middle and high school students, is approximately the same as in Japan, Europe, Singapore, etc.

- Videotaped case studies show that middle school mathematics instruction in Japan and Germany is engaging, inquiry-based, and process-driven for the students while the one in the US relies strictly on the didactic or lecture mode approach [Stiger et al., 1999]. In essence, instruction in Japan and Germany adheres to the teaching standards summarized above [NRC, 1996] while the one in the US does not.

- As compared to their peers in some 52 other countries, *US teachers do not have adequate, job-embedded planning time (a key aspect of continual, professional development).*

One major lesson of TIMSS that seems to have been lost consists of the fact that the above plethora of disjointed topics in US schools has the following direct implications: (a) For the training of US middle and high school teachers, there are approximately 2/3 more topics to cover as compared to the case of their counterpart in Japan and Germany; hence, unless the equivalent 2/3 more time is spent by the US pre-service teachers on their numerous topics, their level of comfort or mastery will be far less than that of their peers in Japan and Germany; (b) in their classrooms, US middle and high school teachers have 2/3 more topics to cover than their counterparts in Japan and Germany; the seat-time in all three countries being approximately the same, the US teachers may have little choice but to superficially discuss (via lectures) the numerous, and disjointed topics imposed by their curricula.

The significant other is the adequacy of the time on relevant learning tasks. This is so for pre-service training of teachers, in-service activities, and reform-guided K-12 instruction. In light of the plethora of topics discussed above, the implementation of this significant other requires, (1) the structured or cognitive condensation of the science and mathematics curricula for middle and high school pre-service teachers and (2) the concomitant condensation of middle and high school science and mathematics curricula. *More importantly, for the thousands of teachers already in fields, the above referenced condensation is of paramount importance if their professional developments are not to be characterized by "splintered vision," given the lack of adequate planning time embedded in their job, and if their classroom instruction is to evolve significantly towards the standards discussed above.* The following overview of selected teaching and learning models further underscores the necessity of the above significant others, in light of the critical importance of "time on relevant tasks."

Selected Teaching and Learning Models

Several models of teaching and learning include the essentials of the point made above relative to the critical need to devote adequate time to properly sequenced subject and skill contents of courses in order to ensure optimum learning outcomes. These models have been reviewed by Huitt [1995]. The role of time is obvious in Carroll's model [Carroll, 1963] that equates school learning with a function of the ratio of the time spent on learning and the time needed. Instructional time and the degree of engagement of the students in the learning process are the main determinants of the "time spent" on learning, according to the model. Time needed is contingent on aptitude (assumed innate), ability to understand (as measured by the possession of prerequisite knowledge), and the quality of instruction. Clearly, Carroll's model incorporates several of the key points made above relative to the time devoted to teaching and learning. Carroll's model does not consider the context of learning, including the influences of parents or guardians, and of the society at large.

Bloom [1971], a colleague of Carroll, introduced the Mastery Learning Model that emphasizes the adequacy of the time given to students to learn and the quality of instruction, including collaborative teaching and the role of corrective feedback. According to Bloom, all students can earn grades of A if the above conditions are met. This assertion has been partly echoed by recent reform blueprints in the form of "all students can learn," without references to the actual proof [Snoddy, 1926; Newel and Rosebbloom, 1981; Bagayoko and Kelley, 1994a].

Proctor's model [1984] differs from the above ones in its introduction of variables germane to the context of learning, including *expectations* and the *social climate at the school*. This climate encompasses attitudes, norms, prejudices or beliefs held by teachers, administrators, and others. While the high expectations recommended by the model could be derived from Bloom's belief that all students can earn grades of A, the influences of teachers' attitude and efficacy are relatively new. Proctor's model goes beyond the ones above by adding the School's social climate as a key determinant of learning. In particular, low expectations are believed to contribute to inadequate learning by the students. This point is partly confirmed yearly in schools with the so-called "ability tracking." In those cases, the inadequate learning is due not only to the impact of low expectations of students but also to the wanting nature of the quality of the subject and skill content of the courses taken by students in the low ability track.

Huitt [1995] presented a comprehensive model of teaching and learning that basically synthesizes and extends several of the previous models. In particular, the model considers characteristics of schools, teachers, teaching, and of students, along with contextual influences. The context of learning, for Huitt, includes "family, community, state and federal government, TV/movies, and the global environment." Further, the model injects a quality factor into the time variable as introduced by Carroll. An extensive and diagram-enhanced discussion of this model and others has been provided on the World Wide Web by Huitt [1995]. In connection with the issue of time, Huitt's model includes not only the time devoted to a subject, but also the extent to which that subject overlaps with or maps the content of applicable tests and the degree to which students are successfully engaged in the learning process. Both Huitt's and Proctor's model subscribe to the construct of "academic learning time (ALT)" as "the amount of time students are successfully involved in the learning of content that will be tested."

The importance of the amount of time devoted to teaching and learning is common to all the models noted above. These models evolved rather naturally, beginning with variables that are totally under the control of the teachers and schools and evolving to include a broader context for teaching and learning. In that sense, their evolution parallels that of the educational reforms discussed above.

The Critical Need of Adequate Time on Relevant Learning Tasks

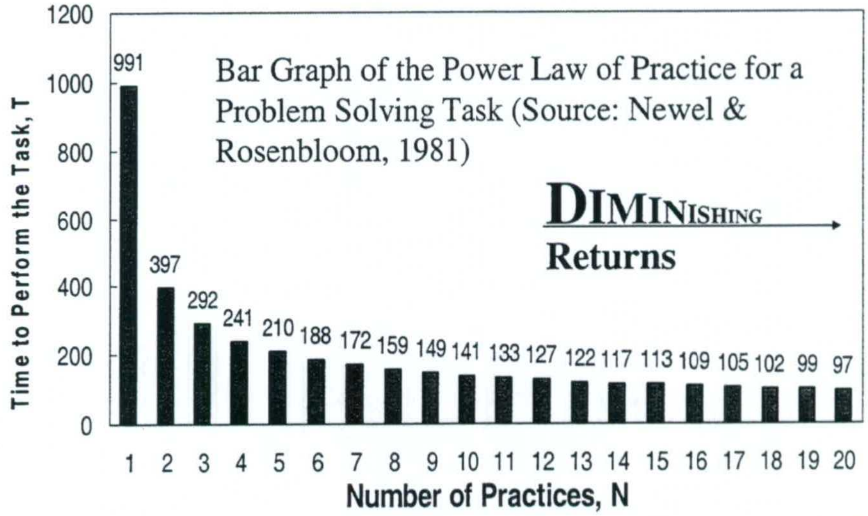
The above review of the teaching and learning models directly pointed to the critical importance of *"adequate time on relevant learning task,"* for pre-service students, in-service teachers, and their students. This importance was underscored by the recommendations of the educational reform blueprints that place emphasis on inquiry-learning, discovery-learning, and an overall engagement of the students in the learning process. The TIMSS reports, however, elucidated the plethora of topics in US middle and high school curricula. We conclude that this multitude of disjointed topics basically constitutes a major roadblock not only to teaching that adheres to the above teaching standards, but also to the proper pre-service training and professional development of middle and high school teachers. While these findings suffice to make the case for a structured or cognitive condensation [Bagayoko and Kelley, 1994b] of curricula and of lessons, a discussion of the Power Law of Human Performance (PLP) or of Practice seems necessary. Indeed, US educational community has practically ignored the report of the National Education Commission on Time and Learning [1994]. Had its recommendations been heeded, this report alone could have led to the changes dictated by the current situation and discussed further below.

Unlike *"Prisoners of Time,"* the final report of the National Education Commission on Time and Learning, the Power Law of Human Performance can no longer be ignored by anyone involved in the process of education. The Power Law of Performance or of Practice (PLP) states that the time (T) it takes an individual to perform a given task decreases as the number of times (N) the individual practiced the task increases [Snoddy, 1926; Newel and Rosenbloom, 1981; Bagayoko and Kelley, 1994a]. In mathematical terminology, the law is:

$$T = A + B\,(N + E)^{-p} \quad \text{or} \quad T = A + B/(N + E)^{p}$$

where A, B, E and p are constants that vary with the task at hand and with the individual performing the task. "A" represents a physiological limit; for a given task, this constant is approximately the same for most individuals. *B and E partly denote prior experiences before the beginning of the practice sessions.* They can be referred to as the Bill Cosby Parenting Factors, inasmuch as they can be drastically different for two individuals, depending on prior exposures and experiences due to or mediated by parenting or the lack thereof. The learning rate is p and it is generally around 0.50 for most task and most individuals. In other words, the law states that *"practice renders perfect."* This law applies to the performance of *sensory-motor (or athletic), creative (or artistic), and cognitive (or intellectual) tasks [Newel and Rosenbloom, 1981].*

The shorter the time T to perform the task - *completely and correctly* - the higher the level of proficiency. *Hence, as the number of practices increases so does the proficiency of the individual.* The figure below graphically shows the plot of the above expression for a problem solving task.



The larger the number of practices (horizontal axis), the smaller the time to perform the task correctly—regardless of gender, ethnicity, socio-economic status or hair style! **THE TIME ON RELEVANT LEARNING TASK IS THE KEY.**

The dramatic impact of this law becomes apparent when one considers its application over several tasks and several days, months, and years. Then it becomes clear that *genius is mostly the result of sustained practice.* The same way adequate practice, at an adequate scope and depth, is needed for the making of Olympic, National Basketball Association, National Football Association, and Major League Soccer champions and for the making of musicians and other artists, the same way it is needed for the making of science, engineering, mathematics, and other scholars.

Further, this law is implacable. It applies whether one likes it or not! It applies to the refinement of the enhancement of the teaching, mentoring, research, and writing skills of a faculty member, a teacher, or of a student! These points are discussed further by Bagayoko and Kelley (1994a) and Moore and Bagayoko [1994] in connection with the explanation of the creation of educational value-added from K through graduate school and beyond.

The integrated or compound law of human performance [Bagayoko and Kelley, 1994a] is the convolution of the power law of performance as *simultaneously applied to several tasks over a long period of time (hours, days, months, and years).* The main difference between the power law and the integrated law (or simply the law) of performance is that the former follows a simple equation that involves an exponent (i.e., the power p) while the mathematical form of the latter is yet to be determined. *The quintessential point here, however, stems from the fact that according to this generalized law of human performance, the abilities, skills, and attributes of students that are meaningfully engaged and challenged in and outside the classroom (as by teaching and mentoring activities) — from K through graduate school and beyond — are the ones that will develop!*

The law of human performance or of practice (LP) provides the scientific basis for high expectations for all students! This point is rigorously established by Bagayoko and Kelley [1994a]. This law also asserts, by virtue of its implacable nature, that a self-fulfilling prophecy is likely to result from the absence of high expectations. The low academic achievements of students tracked in "low ability groups," in any school or state, verify this tautology or self-evidence.

Implementing the Significant Other for Effective Education and Professional Development

A Summary Restatement of the Problem: the significant other

The above discussions of the Law of Practice unambiguously point to the fact that the learner has to spend adequate time learning and practicing any subject content, skill, or process that is not only to be known but also to be mastered. Similarly, any thinking skill that a learner is to develop has to be adequately engaged by teaching in the classroom and outside the classroom through judiciously selected assignments. The above review of teaching and learning models also suggests strongly that the "time on relevant learning tasks" is central to effective teaching and the related learning outcomes. *This demand for time is further exacerbated by the recommendations of the educational reform blueprints.* These recommendations, as partly summarized above, place as much emphasis on process (i.e., engagement, inquiry, problem-solving, thinking, etc.) as on the knowledge of subject content. In Bloom's language, students are not just to know facts, they also have to comprehend, apply, analyze, synthesize, and evaluate.

In light of these requirements for adequate time on learning tasks, the plethora of topics in middle and high school curricula simply constitute a major roadblock not only for reform-guided teaching in K-12 classrooms, but also for the training of pre-service teachers and for the professional development of current teachers. Specifically, the 2/3 extra topics in American middle and high school science and mathematics curricula are simply overwhelming. One direct consequence of this situation, according to teachers facing district and state curricula, consists of a *"fly over approach"* that is the very antithesis of the recommendations of the reform blueprints. Even though the genesis of this situation is not our focus, we could point to the total absence of communication and coordination, before 1989, between the various district and state education agencies that decided on curriculum matters. In this climate, most textbook publishers, in response to the continual advancement in knowledge and in technological developments, appear to have simply added topics and chapters. These curricula that are "a mile wide and an inch deep" naturally drove the activities not only of the teacher training units (colleges of education and departments that provide general or content-specific education) but also the activities of professional development service providers. Interestingly, after 10 years of reforms, many of the standards and curriculum frameworks are yet be reflected, in any meaningful way, in the textbooks that are still weighing the system and the teaching process down while aggravating the need for more time.

From the above points it clearly appears that the significant other for effective education is *"making adequate time for teaching and learning key concepts, skills, and processes."* This requirement applies not only to pre-service and in-service training for teachers, but also to K-12 classroom instruction and beyond. The above findings of TIMSS, however, show the utter inadequacy of the time devoted to science and mathematics topics in American middle and high school as compared to their counterpart in Japan, Germany, and others. We present below proven methods of "making adequate time" by drastically reducing the plethora of topics, in a curriculum or a lesson plan, to sizes that permit exploration, invention, and discovery in the Piagetian sense.

The Solution: Structured or Cognitive Condensation of the Curricula and of Lessons

A thematic approach: Benchmarks and Atlas of Science Literacy

With the problems summarized above with the K-12 science and mathematics curricula in the US, the implementation of reform-imbued teaching and learning methods in K-12 classrooms, in pre-service training, and in professional development activities requires a *structured condensation* not only of the curricula but also of lesson plans. This restructuring is not a simple reduction in size, rather, it is a complex, synthetic rearrangement, linking, and connecting of topics into a much reduced set that lends itself to a teaching that is congruent with the precepts of the reforms and is characterized by extensive hands-on and mind-on in the sense of the Piagetian cycle of exploration, invention, and discovery. Much has been done by the American Association for the Advancement of Science (AAAS) over the last several years. Indeed, this condensation is what is partly meant by "less is more," i.e., an approach that abandons the multitude of disjointed topics for a coherent, thematic one which promotes thinking, understanding, and problem-solving. In particular, the Benchmarks for Science Literacy [AAAS, 1993] and the ATLAS of Science Literacy [AAAS and NSTA, 2001] provide clear roadmaps for the recommended restructuring or cognitive condensation. Given that the trickling down of educational reforms into thinner textbooks, in light of the commercial interests and their interactions with often discordant districts, will take several years, teachers and college faculty members basically have to accomplish this feat without waiting for these thinner textbooks. *It is apparent from the TIMSS reports (Stiger et al., 1999), that teachers for the same grade levels should form teams of 2 or more people to conduct the recommended restructuring of lesson or activity plan.* This team approach significantly enhances the effectiveness of said restructuring or concept mapping.

Structured or Cognitive Condensation and Illustration: Fundamental Forces of Nature

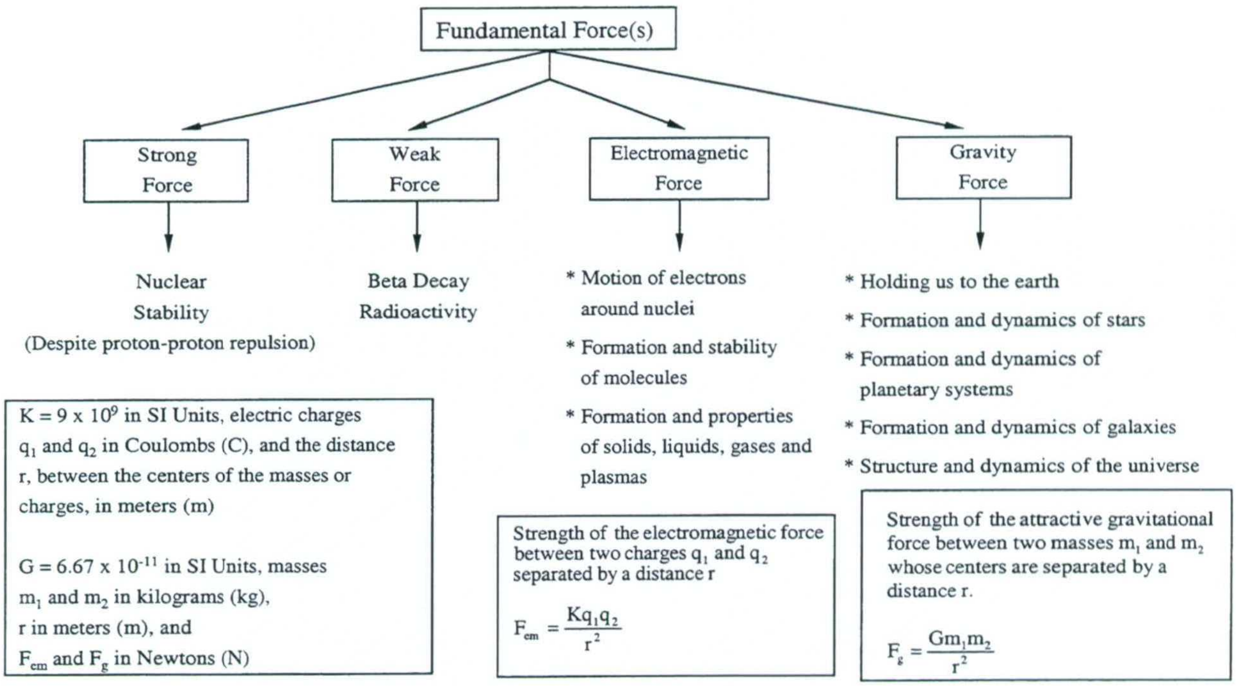
In order to assist teachers and teacher training units to engage significantly in the bunching, clustering that leads to a successful approach that uses themes and strands, Bagayoko and Kelley (1994b) introduced the cognitive or structured condensation. This empowering method, when properly implemented, yields a significant time dividend that could be invested in reform-guided teaching and learning. Specifically, by drastically reducing the large numbers of disjointed topics in a curriculum or a lesson plan to much smaller ones, the method affords the exploration, invention, and discovery of the knowledge and skill contents of these smaller numbers of topics.

A major contribution of Bagayoko and Kelley (1994b) consisted of introducing a practical and fail-safe method for drastically condensing an entire curriculum to its core topics such that, through simple reasoning, one could recover all the subject and skill contents in a curriculum framework, grade level expectations, and the related competencies. These tools of cognitive condensation are in three simple steps that follow.

- **The correctness** (accuracy, precision, & completeness) of the statements of key definitions, concepts, principles, and laws (to avoid misconceptions and to facilitate embedding);
- The explicit delineation of the **domains of validity** of these statements to avoid misconceptions; Explicit applications in diverse situations to promote transfer; and
- **Clustering, bunching, and mapping of concepts and processes** using causal, functional, or logical relationships; this third step is critical if an actual reduction of the numbers of topics is to be attained.

One illustration of the application of these three steps consists of the following concept map of the fundamental forces of nature. This map leads straightforwardly to explanation of the physical reality as we currently know it.

The Fundamental Forces of Nature



It should be noted that no profound understanding of these forces is required to grasp, and profoundly so, their respective roles in explaining the structure of the material universe. In particular, for the strong forces, all one needs to know is that they are very strong and that they act only at very short distances (i.e., distances between protons and neutrons inside a nucleus). Without mention of the strong forces, one should never tell middle or elementary school students about the nucleus and the fact that like electric charges repel each other while unlike ones attract each other. Indeed, protons, that are all charged positively, could possible not be together inside the nucleus had it not been for the strong forces that overcome their repulsion of each other. The formula for the electromagnetic and of the gravitational forces are understandable for middle school students. Only basic operations on real numbers (including some with decimal places) are required for understanding and applying these formulae. We note, however, that this understanding explains the vast arrays of phenomena respectively listed above under these forces. Finally, we should mention that the joining of the arrows for the weak and electromagnetic forces denotes the fact that these forces have been unified (i.e., found to be two manifestations of the same force).

The above map is simply priceless for a professional development workshop for middle or elementary school teachers who deal with physical and other sciences in their classrooms. The map provides a coherent, compact, and comprehensive view of a plethora of phenomena that would otherwise seem utterly unrelated or disjointed. One could naturally expand on various parts of the map to cover numerous rubrics in physical science curriculum frameworks or grade level expectations.

Impact of the Implementation of the Significant Other

Every summer, from 1992 to present, the Timbuktu Academy has been utilizing the above solution to close the academic achievement gaps between its pre-college participants and their peers from any other ethnic group in America. More details are available on the paradigm, programs, activities, and results of the Academy on the web (www.phys.subr.edu/timbuktu.htm). The Academy applied cognitive condensation to pre-college English, Mathematics, and Physics. Consequently, in six weeks, it has been devoting adequate time to each of these subjects to lead to their mastery by the student participants. To be sure of replicating the reality in American classroom, these students are selected so as to cover a wide range of academic preparedness. For instance, their ACT scores range from 15 to 25 out of 36. The concept map shown above is one of several utilized for the physics course these students take. Others include the concept maps on the rate of change, uniform and uniformly varied motions, the projectile motion, Newton's second law, and the work-energy theorem. The cognitively condensed lesson plan on Newton's second law, by itself, thoroughly and coherently covers the content of three different chapters of most high school or college textbook on mechanics, including the ones on impulse and momentum and on collisions.

Similarly, in English, we deviated from the wrong assumption made throughout America relative to high school students' mastery of English in general and of grammar in particular. In fact, many high school English classes do not address English grammar in any comprehensive or verifiable way. Twelve years of practice has shown that if literature were a house, then grammar would be not only it foundation but also the mortar while vocabulary may provide the bricks. The first two weeks of our summer work in English are devoted to grammar. We actually verify, by the end of the second week, that every participant has learned every one of the basic rules! We utilize the remaining four (4) weeks to build the "house," including reading and writing. Similar work is done in mathematics where we begin with the foundational concepts and skills of pre-algebra and algebra. Unlike others, we do not confuse understanding and mastering. While the latter requires the former, it is not reducible to it. The adequacy of the time of learning is further guaranteed with the daily homework assignments that heed the power law of performance and straightforwardly lead to mastery or proficiency.

The extensive results of the Academy, in having its pre-college participants register quantum leaps in their ACT scores and it producing national merit and national achievement scholars, partly led to its receipt of the 2002 US Presidential Award for Excellence in Science, Mathematics, and Engineering Mentoring. While a typical high school year leads to an increase of 2.5 points, the Academy's participants typical register increases between 3 and 10, with several around 4 points. Interestingly enough, the jumps in English are always the largest, on average. This increase in English also favors similar improvements in reading and science reasoning scores. It is important to note that our understanding of the condensation of the curriculum explains the reason we devoted much more time to English, beginning with grammar followed with basics of writing, than to reading and science reasoning. The above results and others buttress our claim of having literally closed the academic achievement gaps between our high school participants and their peers.

We are currently providing workshops throughout the state to interested groups of teachers who are interested in a hands-on and mind-on exploration of the curriculum and lesson plan condensation for mastery teaching and learning, i.e., one that makes adequate time for engaging meaningfully the thinking skills of the learners. Of course, heeding the power law of performance naturally dictates adequate homework assignments (and summer assignments) for the cultivation of mastery. In fact, the same approach is applicable to Praxis exam preparation activities.

Summary

Our review of educational reforms, TIMSS findings, teaching and learning models, and of the power law of performance of cognitive science and its extension, the law of human performance or of practice, underscored the quintessential importance of the adequacy of the time on relevant learning tasks for effective education. We illustrated, with examples, the implementation of our solution consisting of meaningfully condensing the plethora of disjointed topics into a set of manageable ones for which the available time is adequate for reform-guided classroom or professional development activities. These classroom activities are augmented with regular, graded homework and summer assignments that further heed the law of practice. The example of the Timbuktu Academy shows that academic achievements gaps can indeed by closed, by design.

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References

American Association for the Advancement of Science (AAAS, 2001) and National Science Teachers Association (NSTA). *Atlas of Science Literacy.* This Atlas was jointly published by AAAS and NSTA, Washington DC, USA.

American Association for the Advancement of Science (1993). Benchmarks for Science Literacy. See also *Blueprints for Reform: Science, Mathematics, and Technology Education*, 1998; Oxford University Press. http://www.project2O6l.org/tools/

American Association for the Advancement of Science (AAAS), Washington, D.C., USA (1989). *Project 206: , Science for All Americans.*

Bagayoko, D., and E. L. Kelley (1994a). *The Dynamics of Student Retention, a Review and a Prescription*, Education, Vol. 115, No. 1, 31-39.

Bagayoko, D and Kelley, E.L. (1994b). *Cognitive Condensation for Mastery teaching and Learning,* Education, Vol. 115, No. 1, 19-25.

Bloom, B. (1971). *Mastery learning*. New York: Holt, Rinehart, & Winston, Inc.

Boof, K.R.., L. Kaufman and J.P. Thomas (1986). *Handbook of Perception and Human Performance, Vol. II, Cognitive Processes and Performance*, John Wiley and Sons, 28-61 to 28-71.

Carroll, J. (1963). *A model for school learning*. Teacher College Record, 64, 723-733.

Huitt, W. (1995). *A systems model of the teaching/learning process*. Valdosta, GA: College of Education, Valdosta State University.

Moore, W. and D. Bagayoko (1994). *A Paradigm of Education: The Model of the Timbuktu Academy*, Education, Vol. 115, No. 1, 11-18.

National Council of Teachers of Mathematics. 1989. *Curriculum and Evaluation Standards for School Mathematics*. Reston, Va.: National Council of Teachers of Mathematics.

National Education Commission on Time and Learning (NECTL, 1994). *Prisoners of Time: The final report of the NECT* (http://www.ed.gov/pubs/PrisonersOfTime/index.html). NECTL, 1255 22nd Street, NW, Washington, DC 20202-7591, Telephone: (202) 653-5019.

National Research Council. 1996. *National Science Education Standards.* Washington, D.C.: National Academy Press.

National Science Teachers Association (NSTA), Washington, D.C., USA (1990). *Scope, Sequence, and Coordination (SS&C).*

Newell, A. and Rosenbloom P. S. (1981). "Mechanisms of Skill Acquisition." Edited by Anderson, J. R. Hillsdale, N. J.: Erlbaum

Proctor, C. (1984). *Teacher expectations: A model for school improvement*. The Elementary School Journal, 469-481.

Snoddy, G. S. (1926). *Learning and Stability*, Journal of Applied Psychology, 10, 1-36.

Schmidt, William H., Curtis C. McKnight, Gilbert A. Valverde, Richard T. Houang, and David E. Wiley (1997a). *Many Visions, Many Aims: Volume 1: A Cross-National Investigation of Curricular Intentions in School Mathematics*. Boston: Kluwer Academic Publishers.

Schmidt, William H., Curtis C. McKnight, Gilbert A. Valverde, Richard T. Houang, And David E. Wiley(1997b). *Many Visions, Many Aims*: Volume 2: *A Cross-National Exploration of Curricular Intentions in School Science*. Boston: Kluwer Academic Publishers.

Schmidt, William H., Curtis C. McKnight, Senta a. Raizen (1997c). *Splintered Vision: An Investigation of U.S. Science and Mathematics Education.* Boston: Kluwer Academic Publishers.

Stiger, James W., Patrick Gonzales, Takako Kawanaka, Steffen Knoll, and Ana Serrano (1999). *The TIMSS Videotape Classroom Study: Methods and Findings from and Exploratory Research Project on Eighth-Grade Mathematics Instruction in Germany, Japan, and the United States.* Washington, D.C.: U.S. Government Printing Office.

U.S. Department of Education (1996). Pursuing Excellence: *A Study of U.S. Eight-Grade Mathematics and Science Teaching, Learning, Curriculum, and Achievement in International Context.* Washington, D.C.: U.S. Government Printing Office.

U.S. Department of Education (1997). *Pursuing Excellence: A Study of U.S. Fourth-Grade Mathematics and Science Achievement in International Context.* Washington, D.C.: U.S. Government Printing Office.

U.S. Department of Education (1998). *Pursuing Excellence: A Study of U.S. Twelfth Grade Mathematics and Science Achievement in International Context.* Washington, D.C.: U.S. Government Printing Office.

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Mapping Basic Mechanics Concepts

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Abstract

We recall some essential recommendations of prevailing educational reform blueprints. We underscore the lesson woefully missed by reports of the Third International Mathematics and Science Study (TIMSS) to underline the need for applying "less is more" or More in less" to the design of both curricula and lesson plans. We review the empowering procedure of cognitive or structured condensation for the implementing "More in less." We then discuss illustrative maps of basic concepts in introductory mechanics for mastery teaching and learning. These maps are not only applicable to the teaching and learning of Advanced Placement mechanics courses at the pre-college level, but also to those of introductory college mechanics – for both calculus and non-calculus based courses.

Introduction: The Reform-Implied Rationale for this Work

The aim of this work is to provide examples of concept maps that significantly convey the scope and depth of related physics concepts, principles, and laws in a manner congruent with the precepts enunciated in some prevailing educational reform blueprints. According to the Educational Policy Commission (EPC, 1961), a central purpose of education is the development of students' ability to think. This purpose is echoed by current educational reform blueprints that include the Standards of the National Council of Teachers of Mathematics (NCTM, 1989, 1991, and 1995), Science for All Americans (Project 2061) and the Benchmarks of the American Association for the Advancement of Science (AAAS, 1989 and 1993), Scope, Sequence and Coordination (SS&C) of the National Science Teachers Association (NSTA, 1990), and the National Science Education Standards (NSES) of the National Research Council (NRC, 1996). Common features of these blueprints include their agreement on some fundamental aspects of teaching and learning. A few of these essential features follow.

(a) The development and enhancement of students' ability to think and to solve problems (Bagayoko et al, 2000) is viewed to be as important as any other possible outcome, including the knowledge of some subject and skill contents. In the language of the Bloom taxonomy (Bloom, 1956) the desired outcomes of learning are far from simply being *knowledge*; they also include *comprehension, application, analysis, synthesis*, and *evaluation*.

(b) Curriculum theme and strand approach to teaching is preferred to frenetic and superficial coverage of a plethora of topics that often seem quite disjointed, even to the informed ones. Additionally, the emphasis on the development of the rational powers or thinking skills (Bagayoko and Kelley, 1994a) of the students basically requires this approach for the reason given below.

(c) As much emphasis is to be placed on the process of learning (and of solving problem) as on the knowledge of pertinent subject contents. To do so requires a different utilization of the classroom time to include activities that *genuinely engage the rational powers of the students* (in and outside the classroom, as through judicious assignments). According to Bagayoko and Kelley (1994a), the compound law of human performance clearly shows that the cognitive and behavioral attributes that are engaged by the teaching and learning process (in and outside the classroom) are the ones that develop favorably, irrespective of what someone may wish. *With a plethora of topics, such a meaningful engagement is generally not possible, due to time constraints. This assertion also holds for pre-service or in-service teacher training activities.*

(d) Relevancy, as partly implicit in the problem-solving activities noted above, is another central recommendation of the referenced reforms. Hence, applications of the subject content knowledge and skills to situations or contexts that are relevant or familiar to the students are preferred, whenever possible. (Provided that one looks enough and consults colleagues, such contextual problems and assignments can generally be found.)

(e) Feedback processes (i.e., outcome assessment, testing, etc.) that are congruent with the above items are naturally needed. When tests focus solely on recall, they effectively force the average student to equate learning to rote memorization. Learning entails much more than memorizing. Recalling is only one of the ten (10) rational powers or thinking skills identified by EPC (1961).

This last point, (e), is not to be construed to mean that some memorization is not needed or necessary. After all, thinking often entails relating and, as such, requires understanding and knowing (as in correctly recalling) some key concepts, definitions, principles, and laws that are to be related or applied. The points in (a) through (e) underscore the urgency for engaging students' analytical skills, imagination, and creativity, as opposed to just their memorization attributes. To do so requires that a teacher play a pivotal role in guiding students in such a fashion that they reduce to the bare minimum (something they cannot wait to do) the amount of information to memorize. The reader is urged to peruse the noted reform blueprints as they contain several other pertinent recommendations we cannot address here. In particular, the National Science Education Standards, somewhat a synthesis and extension of most of the other pre-college, science reform blueprints, discusses not only science subject and process *content* for the various grade levels, but also *teaching, outcome assessment, professional development, science programs*, and *science education systems*. Except for the content standards, the remaining five (5) standards are directly transferable to the undergraduate and graduate levels!

The key lesson that has been missed by reports on the Third Mathematical and Science Study (TIMSS) consists of the following: *While US middle and high schools have approximately the same numbers of classroom days or weeks as their counterparts in some 52 other participating countries, their science and mathematics curricula contain approximately three (3) times the number of topics in Japan, Germany, and other countries.* Consequently, when considering the time spent on a given topic, it is misleading, if not simply erroneous, to suggest that US middle and high school students devote adequate time to their science and mathematics subject and skills contents as compared to their peers in Japan or Germany. This point, to our knowledge, has not been cogently noted by TIMSS reports. Some of these reports quote the comparable nature of time (i.e., seat-time) devoted to the entire science and mathematics curricula in the US, Japan, and Germany and proceed to assert misleadingly that there is "no silver bullet." Schmidt et al (1997) characterize the middle and high school science and mathematics curricula to be "a mile wide and an inch deep." The TIMSS achievements actually point to the above missed lesson. Indeed, while US 4th grade students ranked around the top among their peers, the US 8th and 12th graders respectively placed around the middle and the bottom in comparison to their peers. We conjecture, with good reasons, that spending 2/3rd less time in class on individual topics as compared to their Japanese and German peers explains a good deal of the poor and poorer ranking of the US middle and high school students. Incidentally, the poorer ranking at the high school level partly reflects the compounding of the exposure and practice deficit that starts in middle school! We should note that the large number of topics in U.S. curricula is a formidable roadblock not only to reform-imbued, standard-based teaching, as recommended by the reform blueprints, but also for meaningful pre-service and in-service training of teachers in the subject content. It is critical to note that the coherent, condensed curricula in Japan and Germany actually cover the same scope as the US curricula; they do so without breaking topics into a plethora of disjointed ones whose large numbers constitute a major problem in the US.

- Hence, this situation strongly supports a focused and coherent curriculum, a natural outcome of the proper implementation of the noted reforms. Such a curriculum can be developed using "less is more" and a thematic approach as clearly explained in some reform blueprints that include the Benchmarks (1993) and Atlas for Science Literacy (AAAS, 2001). Bagayoko and Kelley (1994b) introduced the empowering concept of *cognitive or structured condensation* that enables the development of reformed curricula and of classroom activity plans. Many efforts at the national and state levels continue to be devoted to the design of new curriculum guides or frameworks that adhere to the basic precepts of the reforms.

Prisoners of Time, the final report of the National Education Commission on Time and Learning (NECTL, 1994), directly supports or guides the above reform blueprints. Indeed, the quintessential issue of the proper utilization of teaching and learning time, as intimated above, points to the need to reduce drastically the number of science and mathematics topics covered in American middle and high schools. This number is at least twice as large in the U.S. as the corresponding ones in Japan and in Germany (TIMSS, 1996 and 1998) for middle and high schools. While needed, "seat time," as defined by the Commission, is utterly inadequate for rendering a judgment on time utilization; the scope, depth, organization of the subject and skill content discussed and the level of participation or of engagement of students in the process are among the real determinants. Issues are further compounded, in cases of comparison between the U.S. and Japan, by the extensive after-school learning in Japanese jukus, starting as early as the fourth grade (NECTL, 1994). Consequently, the suggestion by several TIMSS reports of the adequacy of the time devoted to science and mathematics in U.S. middle and high schools is seriously flawed—until such a time where the US middle and high school science and mathematics curricula are condensed to levels that as comparable to those in Japan and Germany.

The preceding overview of some key tenets of educational reforms serves as a rationale for the instructional activity planning and teaching methods illustrated below. The importance of these examples partly resides in their appropriateness in the implementation of reformed-teaching and learning in a fashion that heeds features (a) through (e) of educational reforms as summarized above. As such, the examples directly constitute an implementation of "less is more" (AAAS, 1989) or of "More in less" (Bagayoko et and Kelley, 1994b). Concept mapping (Starr and Krajcik, 1990; Prankratius, 1990), using *the causal, functional, and logical relationships* of cognitive condensation (Bagayoko and Kelley, 1994b; Bagayoko et al, 2005), was the main tool for generating these examples. This approach allows a teacher or instructor who is well versed in a given subject area to "reduce," via concept mapping, the number of disjointed topics to a very small set that literally links and embeds the numerous topics and directly enables reformed-teaching. Of course, such condensation tasks are actually best carried out by teams of teachers. The resulting curricula (and lesson plans) *can be made to encompass totally any reasonable, state or national curriculum guide or framework.* The best part, to be borne out through practice, is the expected, superior academic achievements and performance of the students [on classroom tests and standardized, criteria-referenced, norm- referenced, or AP examinations.

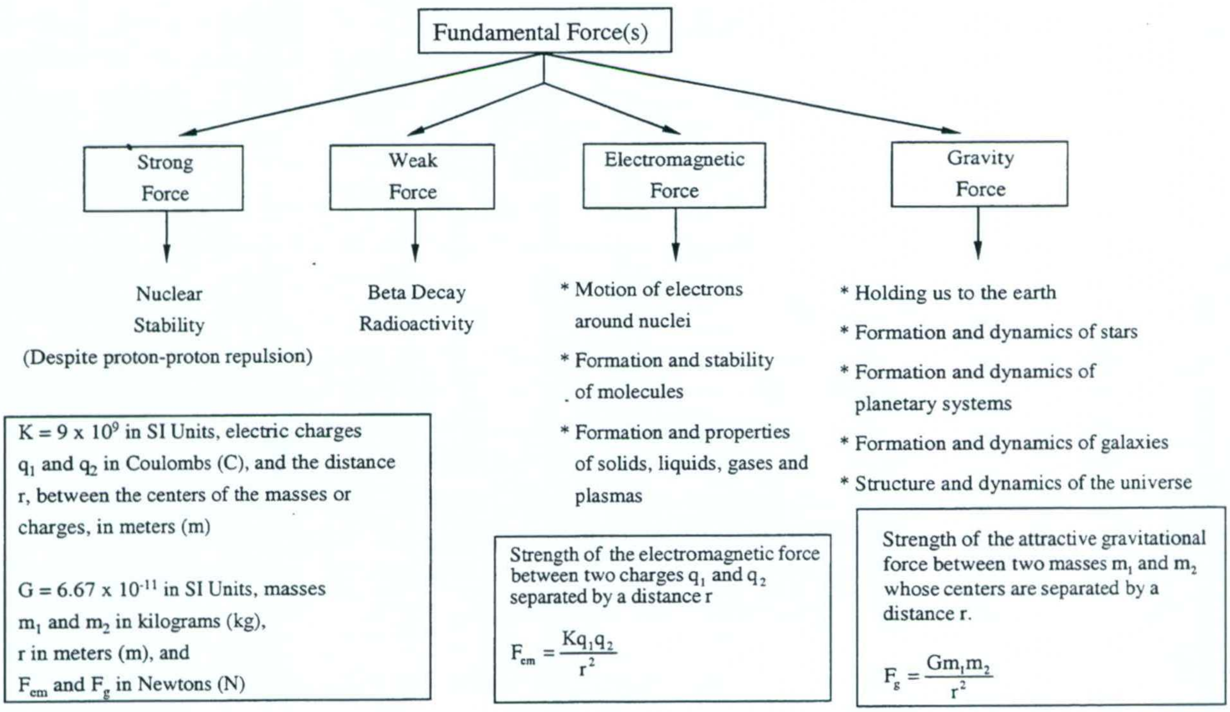
Maps of Basic Concepts in Mechanics

The Fundamental Forces of Nature

The first of our concept maps, on the fundamental forces of nature, has been successfully adapted and utilized to teach physics and related sciences to middle through college students! As per the meaning of sequence in SS&C (NSTA, 1990), differences for the various levels were made in the refinements, questions in the Socratic dialogues, discussions, and assignments. Essentially, the phenomenological approach in the shown map yields to more mathematical intricacies beyond the college sophomore level. The map, for middle school level, is shown on the next page. The level of sophistication can be easily increased with that of the grade level of the students as noted below.

The middle and high school students who actively learned this concept map were participants in the annual, summer, academic enrichment programs of the Timbuktu Academy (Bagayoko, 1999c). *It is pivotal to note that this concept map and the others that follow it are not necessarily the first subject or topic to discuss in class.* On the other hand, the teacher should have the maps *to guide* every activity in such a fashion that students end up with the necessary knowledge and skills to draw them. Concept mapping lends itself to fruitful group or collaborative learning activities. This is not just true for students, it also holds for teachers and college faculty members.

The Fundamental Forces of Nature



We utilize this map to introduce the fundamental forces in a highly interactive manner, using Socratic dialogues. For the middle school, the discussion of the strong forces is limited to two key characteristics: a) they have a very short range and b) they are very strong. Students have to find, through questioning, that these forces are responsible for nuclear stability, given the huge (electromagnetic) repulsion between protons on top of each other in nuclei! The map is utilized to show how the gravitational forces explain the formation and motion of stars, planetary systems, and galaxies and the fact that it is the force of gravity (gravitational force) that keeps our feet to the ground on Earth. The other forces are similarly discussed, with emphasis on the electromagnetic forces and the many phenomena they explain. The similarity between planetary motions around stars (i.e., the sun) and that of electrons around the nuclei is noted—despite the differences between the forces causing them. The striking similarity between the mathematical expressions of the electromagnetic forces and of the gravitational forces is naturally examined. So is the difference residing in the fact that while gravitational forces are always attractive, electromagnetic forces are repulsive for like charges. A great contrast between the expression of the strengths of the gravitational forces and those of the electromagnetic ones is revealed with a series of questions and answers. The key is to have students realize the very large and very tiny values of the coupling constants K and G, respectively. We get students to calculate the magnitudes of the electromagnetic and gravitational forces for unit charges, unit masses, and unit distances (r) to make the point very effectively! Students are challenged, through questions and assignments, to realize that for a non-negligible gravitational force, it is often necessary to have at least one of the masses to be very large. The electromagnetic forces between electrons, atoms, or molecules are used to discuss the existence and many properties of the different states of matter, including an explanation of how the increase in the thermal energy of constituent atoms or molecules can lead to the transformation of one state of matter to another, i.e., from solid to liquid and from liquid to gas. The long-cherished goal of the unification of fundamental forces is mentioned and it is pointed out that the electromagnetic and weak forces have been unified into a single, electro-weak force as signified on the map. It does not hurt to note that the electric and magnetic forces have been unified much earlier, by the Maxwell's equations, into the electromagnetic force.

The refinements of this basic map are elegantly adaptable to the level of the students. Our high school students discuss the centrifugal forces that arise from rotation. It is clearly conveyed to them that these forces are not fundamental and can be easily understood as a form of "reaction or resistance" force inherently associated with the rotation caused by centripetal forces of gravitational or electromagnetic nature. These discussions begin with the question as to why planets are not rushing to their stars, in light of the gravitational attraction. At the college sophomore level and above, the phenomenological Coulomb type formula for the electromagnetic force is replaced by the microscopic, Maxwell's equations. College upper classmen add basic quantum mechanical equations to the latter for the description of particles while they are inside atoms, molecules, solids, or quantum confinements. The map, at the graduate school level, utilizes the Einstein equations for gravity, the relativistic formulation of Maxwell's and of basic, quantum mechanics equations.

Concept Maps of Newton's Second Law of Motion (Translation and Rotation)

As prescribed by cognitive condensation (Bagayoko and Kelley, 1994b), in order to avoid misconceptions, it is essential to delineate explicitly the domains of validity of each law. In the concept map, it is stated that Newton's second law of motion applies universally to all external forces such as gravitational, electromagnetic ones. The universality of the law vis à vis the (chemical) nature of the substance is illustrated with examples. The delineation of the domain of validity (Bagayoko and Kelley, 1994) of the law is critical. It is valid for non-quantum mechanical situations only, i.e., it does not apply to the motion of a particle (i.e., an electron) while it is a part of an atom, a molecule, a solid, etc. In addition, for the second law to apply, the speeds of the particles must be much lower than the speed of light in vacuum. Exercises are assigned to help students appreciate the judgment to be made in determining "much lower." While values of the speed 100,000 times smaller than the speed of light in vacuum are acceptable in some academic problems, the critical point is to have students arrive to the conclusion that "much lower" is partly determined by the problem at hand and the needed degree of accuracy. We always utilize these discussions to recall the absurdity that may result, and that is rarely noted in textbooks, when $v = v_0 + at$, where "a" is the acceleration, is allowed to evolve indefinitely; one gets values of v much larger than c, the speed of light in vacuum!

It is important to point out that the second law, correctly stated in terms of the linear momentum, leads directly to the law of conservation of the total linear momentum in the case where the sum of all external forces is zero.

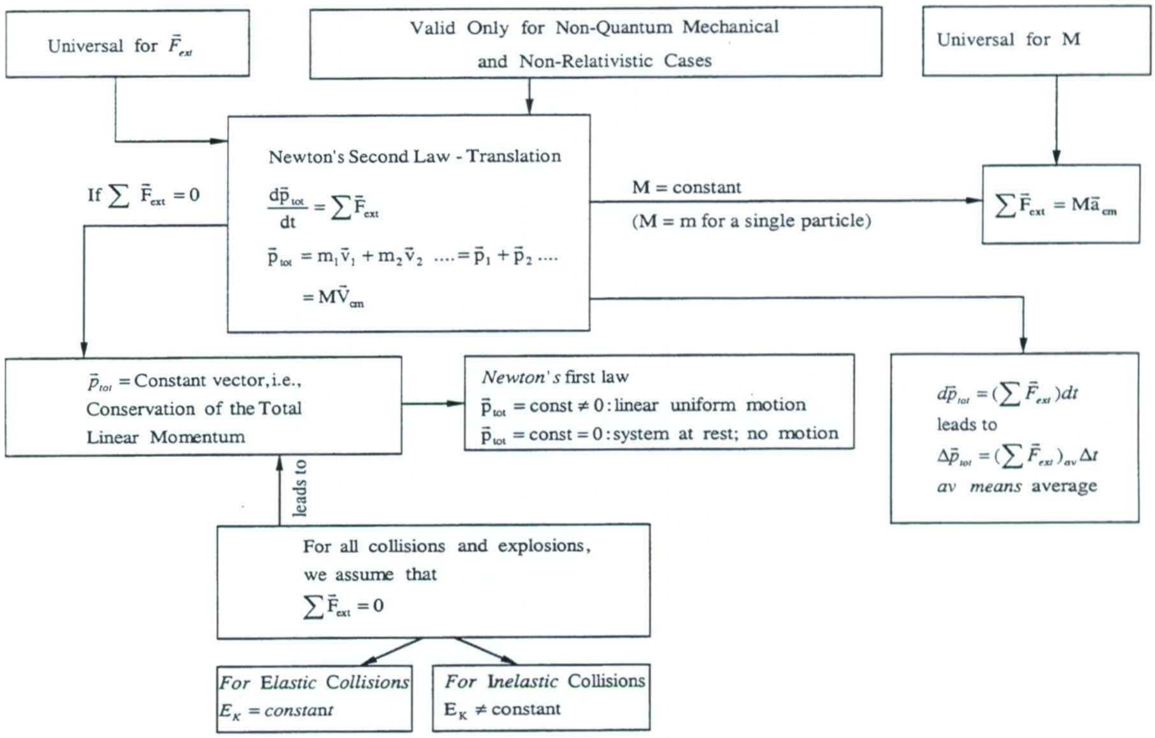
$$\sum \vec{F}_{ext} = 0 \Rightarrow \frac{d\vec{P}}{dt} = 0 \text{ or } \vec{P} = \text{constant}.$$

Once this is understood, the treatment of collisions becomes a trivial matter. With the above knowledge, an understanding of basic operations on vectors and of the definitions of the elastic and inelastic collisions leads average students to solve most problems on collisions, provided they know the key assumption: *"for all collisions, we assume the sum of the external forces acting on the system of colliding particles to be zero."* For the last seven (7) summers, 10^{th} through 11^{th} graders have concluded, with the above assumption, that the total linear momentum is indeed conserved for all collisions.

Using our map of the concept of change (Bagayoko et al, 2005), high school students derive the common expression of Newton's second law for cases where the mass is constant (and hence dm/dt=0 or dM/dt=0). This common expression, $\sum \vec{F}_{ext} = M\vec{a}$, does not lead students to the discovery of the law of conservation for the linear momentum, in general, or in cases of collision, in particular. A proper statement of the second law also leads to the understanding of impulse $\Delta\vec{p}_{tot} = \sum (\vec{F}_{ext})_{av} \Delta t$ and related, practical applications to calculations of average forces. "Impulse and momentum," unlike the case for several current textbooks, is not the subject of a chapter in our approach!

The concept map of Newton's second law for rotation can be easily derived from the one shown here for translation. The construction and discussion of this map, for rotation, is a homework assignment for college students. This map for rotation can be similarly utilized to derive several important results that include the conservation of the angular

A Concept Map for Newton's Second Law (Translation)

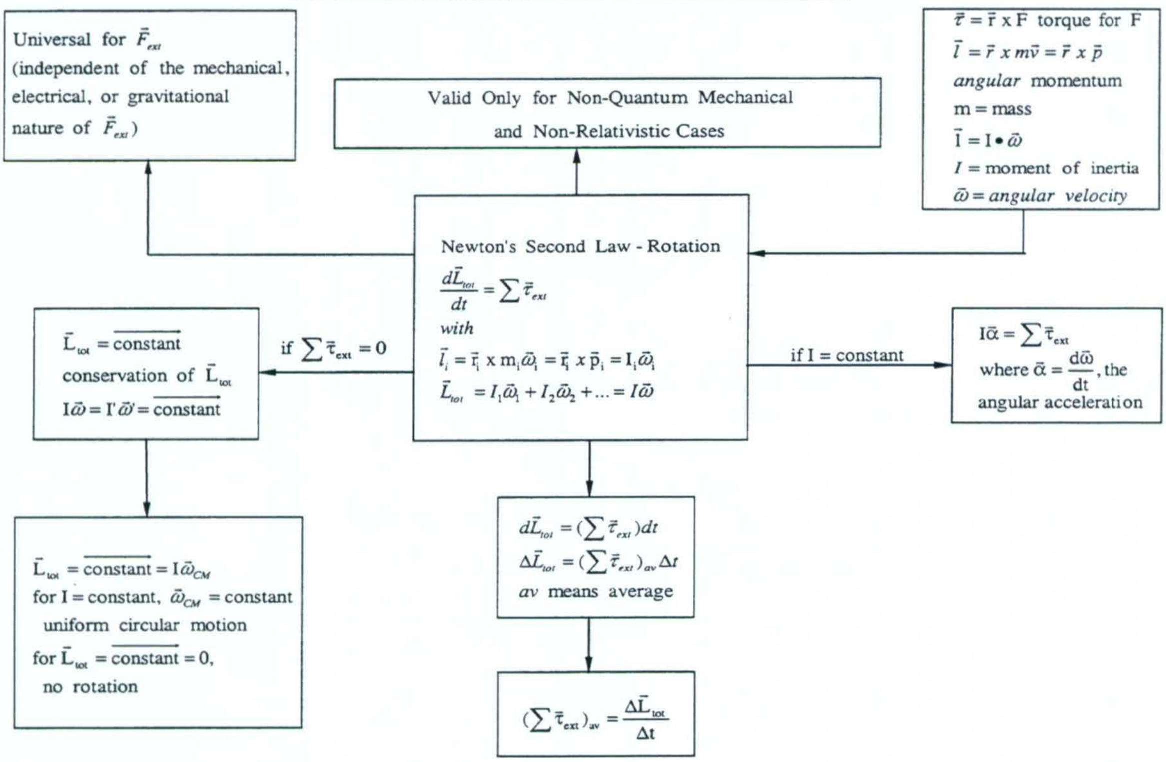


momentum when the net external torque applied to the system is zero. Our concept map for translation deliberately avoids any suggestion of a major dichotomy between the case of a single particle and that of a system of particles. The additive property of momenta and of masses (m) leads to the definitions of the total mass (M) and of the velocity of the center of mass for a system of particles. The well-versed students, including high school ones, have not had any problem drawing the map for either case.

Naturally, these maps of Newton's second law, for translation and for rotation, directly lead students who mastered them to the discovery of the law of static equilibrium. Indeed, when the some of the external forces and the sum of the external torques acting on an object or system are both zero, then that object or system is in static equilibrium! Hence, another chapter of standard textbooks appears as a trivial corollary of Newton's second law. While static equilibrium is the subject of extensive applications (in and outside the classroom) that may take one hour or more of classroom activity, we do not treat it as an independent chapter. Several years ago, we dropped a textbook that, one edition after another, continued to cover static equilibrium in a chapter before that for Newton's second law; it also enunciated this law only in its common forms, in terms of accelerations, that do not lead students, straightforwardly, to critically important conservation laws for the linear and for the angular momenta.

A pivotal refinement of this map, for college junior and senior levels, consists of having an arrow from Newton's second law for translation to a new box. This box is to contain the application of the second law to an element of a vibrating rope, for example, to generate the wave equation. This branch of the map will then show that the second law leads straightforwardly to the prediction of mechanical waves, a situation analogous to the prediction of electromagnetic waves by Maxwell's equations, or of gravity waves by the Einstein equations.

A Concept Map for Newton's Second Law (Rotation)

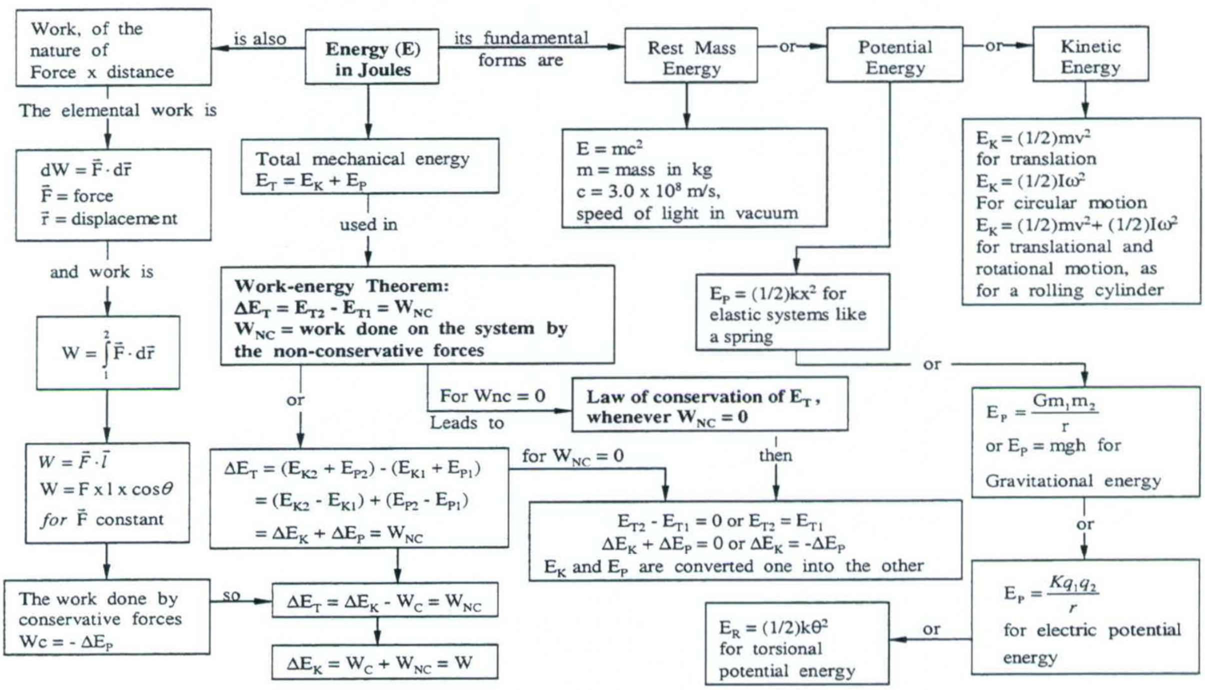


Concept Map of the Work-Energy Theorem

The concept map for the work-energy theorem provides a clear example where some instructional and learning activities have to precede the drawing of the map. This situation arises due to the relative importance of several concepts that appear in the map. Kinetic energy, potential energy, work done by conservative and non-conservative forces, and the derivation of conservative forces from a potential should be discussed, applied, and assigned in homework before attempting to draw the following concept map for the work-energy theorem.

Further, we find it somewhat disappointing that many publishers or authors continue to state this theorem only by equating the change in the kinetic energy to the total work done on a system (or a particle) by external forces. Surely, they know that situations in which this formula is true are also situations where the formulation given in this concept map holds. Namely, the main formulation of the work-energy theorem in the concept map states *that when a system moves from configuration or position 1, with a total mechanical energy* E_{T1}*, to configuration 2 with* E_{T2}*,* *then the change in the total mechanical energy of the System, delta (E_T) or $\Delta(E_T)$, is equal to the work done on the system by the non-conservative forces (in going from position 1 to position 2).* The map shows that this formulation leads to the one in terms of the change in the kinetic energy of the system. More importantly, however, our formulation empowers students to be in position to know when the total energy of a system is conserved. The work-energy theorem, when stated in terms of the work done by non-conservative forces (W_{NC}), does indeed lead straightforwardly to the law of conservation of the total mechanical energy. Namely, from $E_{T2}-E_{T1}=Wnc$, it follows that $E_{T2}=E_{T1}=$constant, whenever Wnc is zero. Of course, in such a case, $\Delta E_K + \Delta E_P = 0$, with $\Delta E_K = -\Delta E_P$. The famous conversion of potential energy into kinetic energy and vice-versa, as it occurs for a simple pendulum or an ideal, frictionless roller-coaster, becomes trivial.

A Concept Map for the Work-Energy Theorem



This concept map succinctly shows different forms of the potential energy, including gravitational and elastic ones [$E_P = mgh, E_P = (\frac{1}{2})kx^2, E_P = (\frac{1}{2})k\theta^2$]. The map therefore precludes the "implicitly suggested" belief on the part of some students that E_P = mgh is applicable in all situations. Similarly, the map clearly shows the general, non-relativistic expression of the kinetic energy for translation, rotation, and their combination –as is the case for a rolling cylinder.

Upon mastering this map, that can be easily reproduced using "reasoning" memory, our high school students have utilized it to solve many kinds of mechanics problems, beginning with vertical, free fall and projectile motion, inclined plane, and simple pendulum problems. They also solved complex, dynamic problems with or without friction (the common, non-conservative force). Our experience with Advanced Placement (AP) examinations in classical mechanics indicates that no less than half of the mechanics problems can be trivially solved by a student who understood and learned this concept map. Of course, the student will have to realize that numerous, kinematics problems, in addition to dynamics ones, can be solved by using the work energy theorem as formulated here! Some exercises could easily alert the student to the fact that the mass m, if unknown, cancels out in most of these problems.

Conclusion

We discussed examples of concept mapping that heed some cognitively and behaviorally sound recommendations of educational reforms. These examples illustrate the opportunities offered by this approach to engaging the thinking skills (or rational powers) of the students from the onset. Additionally, they immensely reduced the number of lessons (i.e., chapters and topics) that would have otherwise been needed to treat the vast number of topics that are linked and bunched by the concept maps. In the case of introductory physics at the college level, these maps allowed us to treat meaningfully the contents of several chapters in usual textbooks, including the ones on collisions, static equilibrium, impulse and momentum, and on the conservation of the total mechanical energy, without presenting them as independent chapters. We do so while ensuring superior learning by students, as attested to by their performance as compared to that of students whose instructors follow these chapters and their ordering as in many textbooks. The above examples are partly intended to illustrate the tremendous gains that could result from a wide application of the thematic approach to curriculum and course development, as well as the planning and student-engaging implementation of classroom activities as illustrated here. Entire courses, or curricula, in such an approach, are cast in the form of concept maps. A similar mapping is possible for critical skills, including a thorough grasp of vector operations in the case of college level mechanics.

Acknowledgments

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References

American Association for the Advancement of Science (AAAS), 1989. Science for all Americans: Project 2061. AAAS, 1333 H Street, N. W., Washington, D.C.

American Association for the Advancement of Science (AAAS), 1993. Benchmarks for Science Literacy. Oxford University Press, New York.

American Association for the Advancement of Science (AAAS), 2001. Atlas for Science Literacy. AAAS, 1333 H Street, N. W., Washington, D.C.

Accepted for Publication in the Proceedings of the International Conference on College Teaching and Learning, Orlando, Florida, January 2005.

Adamczyk, P., and M. Wilson, 1996. Using concept maps with trainee physics teachers. *Physics Education* 31(6): 374-381.

Bagayoko, D., E. L. Kelley and S. Hasan. 2000. A Problem-Solving Paradigm (PSP). *College Teaching,* Vol. 48, No. 1, pp. 24-27.

Bagayoko, D., S. Hasan, and T. Reese, 2005. Mapping the Concept of Change. Submitted to the Journal of College Teaching and Learning.

Bagayoko, D., 1999c. The Timbuktu Academy: http://www.phys.subr.edu/timbuktu.htm.

Bagayoko, D., E. L. Kelley, 1994a. The dynamics of student retention: a review and a prescription. *Education* 115 (1): 31-39.

Bagayoko, D., E. L. Kelley, 1994b. Cognitive condensation for mastery teaching and learning. *Education* Vol. 115, No. 1, Pages 19-25.

Bloom, Benjamin S., 1956. Taxonomy of Educational Objectives: The Classification of Educational Goals, Handbook I: Cognitive Domain, New York, Longman-Green.

Educational Policies Commission (EPC), 1961. The Central Purpose of American Education. National Education Association (NEA), Washington, D.C.

National Education Commission on Time and Learning (NCTL), 1994. *Prisoners of Time*, Final Report of the Commission. Available from Government Printing Office, Superintendent of Documents, Mail Stop SSOP, Washington, DC, 20402-9328.

National Council of Teachers of Mathematics (NCTM). Curriculum and Evaluation Standards for School Mathematics, 1989; Professional Standards for Teaching Mathematics, 1991; Assessment Standards for School Mathematics, 1995. National Council of Teachers of Mathematics, Reston, Virginia.

National Research Council, 1996. *National Science Education Standards*. National Academy Press, 2101 Constitution Avenue, NW, Washington, D.C. 20418.

Prankratius, William J., 1990. Building an Organized Knowledge Base: Concept Mapping and Achievement in Secondary School. Journal of Research in Science Teaching, Vol. 27, No. 4, pages 315-333.

Schmidt, W. H., C. C. McNight, and S. A. Raizen, 1997. *A Splintered vision: An Investigation of U.S. science and mathematics education.* Dordrecht/Boston/London: Kluwer Academic Publishers.

National Science Teachers Association (NSTA), 1990. Scope, Sequence, and Coordination (SS&C). Washington, D.C.

Accepted for Publication in the Proceedings of the International Conference on College Teaching and Learning, Orlando, Florida, January 2005.

Starr, Mary L. and Joseph S. Krajcik, 1990. Concept Maps as a Heuristic for Science Curriculum Development: Toward Improvement in Process and Product. Journal of Research in Science Teaching, Vol. 27, No. 10, pages 987-1000.

Third International Mathematics and Science Study (TIMSS), 1996. *Pursuing Excellence: A Study of the U.S. Eighth-Grade Mathematics and Science Teaching, Learning, Curriculum, and Achievement in International Context.* NCES 97-198. Washington, D.C.: National Center for Educational Statistics.

Third International Mathematics and Science Study (TIMSS), 1998. *Pursuing Excellence: A Study of the U.S. Twelth-Grade Mathematics and Science Achievement in International Context; Initial Findings from TIMSS.* National Center fir Educational Statistics (Item No. NCES98-049), U.S. Department of Education, Washington, D.C.

Philosophical Foundations for Systemic Mentoring at the Timbuktu Academy

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28 JUNE 2002

"To be systemic, mentoring has not only to be comprehensive; it must also be woven through the core activities, values, and reward systems of an organization or academic department."

Introduction

Established in 1990, the Timbuktu Academy[1] is a research-based systemic mentoring program at Southern University and A&M College in Baton Rouge (SUBR), Louisiana. It is named after the former University of Timbuktu, a bastion of scholarship in the middle of the second millennium. The city of Timbuktu, in Mali, West Africa, is located on the left bank of the majestic Niger River. SUBR is similarly located on the left bank of the mighty Mississippi River.

We define mentoring[2] as the dynamic sum of a host of processes and activities through which the young generation is prepared to take its responsibilities in enabling the continual betterment of life. The somewhat amorphous nature of these activities stems from inherent differences between the sets of mentoring activities at home; in precollege school, college, or graduate school; or in public or private organizations. In all cases, however, mentoring entails communicating substantively, supporting significantly, and challenging appropriately. To be systemic, mentoring has not only to be comprehensive; it must also be woven through the core activities, values, and reward systems of an organization or academic department.

Philosophical Foundations of Systemic Mentoring

The ubiquitous need for mentoring is established diagrammatically in the first document at the Web site noted in the box below. An itemized, retrospective review of the career path of the most successful individual, from the precollege days to professional life, shows the critical role played by mentors in various stages of the continual growth of that individual. *We have not yet found an exception to this pattern!* In particular, the more complex the tasks to be performed, the more critical is the role of mentoring. Learning or doing research in science, technology, engineering, or mathematics (STEM) is an extremely complex process. Hence, the need for mentoring in STEM disciplines, from precollege to graduate school and beyond, is significant, but it has only started to get the attention it needs.

Mentoring a youngster to be a religious leader or a research scientist, if done properly, should be guided by a quasi-exhaustive inventory of critical knowledge and skills that underpin success in these professions. Consequently, the principles enunciated below are to guide the systemic mentoring of a precollege, college, or graduate student in any of the STEM disciplines. Their sum constitutes the paradigm of the Timbuktu Academy for its precollege and college mentoring processes and activities, the aim of which is to produce competitive scientists, engineers, and mathematicians. The principles are based in part on the fact that there is no substitute for mastery of the applicable language, mathematics, science, and engineering subject contents and skills. In a way that complements teaching, mentoring therefore serves to ensure the mastery of these contents and skills while also demonstrating attendant skills that are germane to success in the STEM careers. Succinctly, the following principles constitute the essence of our philosophy of mentoring.

Timbuktu Academy at a Glance
The first document at the Timbuktu Academy Web site provides a comprehensive description of the academy's goals and objectives, the design principles that constitute its paradigm, its component programs, a 10-step guide to systemic mentoring activities, and its results to date. This document provides sufficient details to enable an adaptive replication of the academy at home, at school, in college, in research laboratories, or in public or private organizations.

The Timbuktu Academy is funded by the U.S. Department of the Navy, Office of Naval Research (Grant No. N00014-98-1-0748), NASA (Award Nos. NAG5-8552 and NCC13-00010), and the National Institute of Standards and Technology. Through the Louis Stokes Louisiana Alliance for Minority Participation (Award No. HRD-0000272), the Timbuktu Academy is also funded in part by the U.S. National Science Foundation.

Languages are the vehicles of thought.
This tautology holds for thinking in mathematics, physics, engineering, materials science, or in any other discipline of study. Consequently, our programs and activities pay continual attention to the development and enhancement of *English* and communication skills, from the elementary- grade level to graduate school and beyond.

Mathematics is the language of STEM disciplines.

In fact, anecdotal evidence exists, in many countries, to indicate that the dearth of majors in STEM fields at the college level can be traced to the inadequate exposure of precollege students to the proper sequence of mathematics courses.[3] We therefore place a great emphasis on the enhancement of the mathematics proficiencies of scholars at the academy. For precollege students, this emphasis is credited with over 80% of participants enrolling in college STEM curricula. For undergraduate STEM students, it has enabled successful graduate pursuits, up to the doctorate.

Recognize and respect the hierarchical or taxonomic structure of knowledge in most STEM disciplines.
Specifically, some arithmetic and algebra are needed to excel in calculus, the same way that some basic vocabulary and grammatical rules are necessary to compose meaningful prose. This obvious principle, it turns out, is very often the one violated by students and many programs purporting to prepare them for STEM careers. Namely, a rigorous and professional approach is needed to determine the proper sequence in which STEM knowledge and expertise should be built, depending on the selected field. Many college students and their advisers still continue to deal with this issue in an anecdotal fashion, with dire and often unavoidable consequences. Advisers, we presume, are the ones in a position to know that extreme difficulties in some STEM courses, for a student devoting adequate time to the learning tasks, are often due to an inadequate background and not a lack of intrinsic "smartness."

Before the advent of the printing press and the subsequent growth of formal schooling, academic and nonacademic training mostly occurred in apprenticeship contexts, i.e., mentoring. A general review of sociocultural conditioning, including the acquisition of value systems, suffices to make the point. Our fourth design principle is therefore:

Recognize that mentoring is the coupling between teaching and learning, on the one hand, and between research and education, on the other.
Even in a private corporation, mentoring seems to be the mechanism by which competitiveness is preserved from one generation to the next.

The law of human performance[4] is our extension of the power law of human performance[5-6] or of practice.
The power law of performance or of practice (PLP) is perhaps the most stable of the laws in cognitive science. It states that the time (T) it takes an individual to perform a given task decreases as the number of times (N) the individual practices the task increases. In mathematical terminology, the power law[5] is:

$$T = A + B\,(N + E)^{-p} \text{ or } T = A + B/(N + E)^{p}$$

where A, B, E and p are constants that vary with the task at hand and with the individual performing the task. The constant A represents a physiological limit. The constants B and E partly denote prior experiences before the beginning of the practice sessions, and p is the learning rate. In essence, PLP states that practice renders perfect. This law applies to the performance of sensory-motor (or athletic), creative (or artistic), and cognitive (or intellectual) tasks. The shorter the time taken to perform the task--completely and correctly--the higher the level of proficiency. Hence, as the number of practices increases, so does the proficiency of the individual.

- The law of performance does not need to be explained to anyone in the realm of sport or the arts. Athletic and artistic champions, irrespective of perceived "innate" abilities, are made through practice. Similarly, intellectual giants are made through practice. Indeed, the causal determinants, and not just correlates, of the academic success of a student are first and foremost: the exposure of that student to appropriate sets of courses and the adequacy of the subject standard-based contents and skills in each course
- the competitiveness of the scope and depth of this exposure, as ensured by standard-based teaching, and
- the actual amounts of time the student spends learning, applying, and practicing said contents and skills--in and outside the classroom.

"Appropriate" and "adequate" are objectively defined by competitive standards and not some parochial, uninformed, or self-serving norms or criteria set by individuals. The items are known as the ABC of training. They apply to research training as well. According to the law of performance, socioeconomic status, ethnicity, and gender, among others, are not intrinsic factors that determine the achievement levels of students! Indirect, negative effects of these variables can be avoided by ensuring the ABC of training. The taxonomic structure of knowledge in STEM disciplines exacerbates the need to heed the points spelled out above.

Distributed responsibilities and shared credit
It is the expression of the fact that although the first two points above might mostly be the responsibilities of schools, colleges, and their instructors, respectively, the third is mainly the responsibility of students and their parents. Inasmuch as the choices for the courses are left to students, taking the proper courses, the first item might also be a part of the responsibilities of the learners--even though proper advisement remains that of schools and colleges. This principle leads to a major characteristic of mentoring: It entails supporting significantly, financially and otherwise, and challenging adequately. And, of course, a student who does not make adequate efforts--despite documented and lasting support--is unceremoniously dismissed from the academy. Dropping a student who has repeatedly failed to make the appropriate efforts is not a failure. It is merely setting and upholding standards, the same ones that exist in competitive environments!

Mentoring must never be confused with spoiling. Due in part to our unambiguous ways of setting the standards, the requirements, and the responsibilities, less than 5% of undergraduate participants have been dismissed in the last 10 years. In fact, even for our precollege students, it seems that most youngsters--including the ones who might be labeled as "bad"--are begging for the appropriate challenges from adults!

Conclusion

The design of the program components and of the learning and research activities of the Timbuktu Academy strictly and rigorously adheres to the principles set out above. This professional adherence is what makes the Timbuktu Academy beget scholastic and research excellence by design, in a fail-safe fashion. The 10-step Systemic Mentoring Model of the academy, as derived from these principles, is described at its Web site, which also addresses the academy's results of the last 10 years.

References

1. The Timbuktu Academy (http://www.phys.subr.edu/timbuktu.htm), 2001. The very first document at this site provides extensive details on the paradigm and results of the Timbuktu Academy.
2. D. Bagayoko, R. L. Ford, E. L. Kelley, Fundamentals of Mentoring and Networking, in *Scholarly Guideposts for Junior Faculty* (Quality Education for Minority Network, Washington, D.C., USA, 1999).
3. Global Education Database and online resource: United Nations Educational, Scientific, and Cultural Organization (UNESCO) and the U.S. Agency for International Development (U.S.-AID): http://www.usaid.gov/educ_training/ged.html or http://qesdb.cdie.org/ged/index.html
4. D. Bagayoko and E. L. Kelley, The Dynamics of Student Retention: A Review and a Prescription, *Education* **115** (1), 31-39 (1994).
5. A. Newel, and P. S. Rosenbloom, Mechanisms of Skill Acquisition and the Law of Practice, in *Cognitive Skills and Their Acquisition*, J. R. Anderson, Ed. (Erlbaum, Hillsdale, New Jersey, 1981).
6. K. R. Boof, L. Kaufman, J. P. Thomas, *Handbook of Perception and Human Performance, Vol. II, Cognitive Processes and Performance* (John Wiley and Sons, New York, New York, 1986), pp. 28-71.

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PREPARING FOR GLOBAL COMPETITIVENESS

Utilizing Internet tools in Research, Learning, and Teaching

D. Bagayoko, Ph.D. (Bagayoko@aol.com)

The Internet is perhaps one of the most ubiquitous factors in the growing globalization. The proper utilization of this formidable tool in research, learning, and teaching provides a distinct competitive advantage. Sound judgment, it appears, is a condition for maximizing its benefits.

Introduction: Imperatives for a Growing Motivation for Actions

Since its appearance in 1991, the Internet has been growing very rapidly – While some private and public entities did not have highly informative and user-friendly websites in 1995, practically all-major ones in the United States of America did by 2003. For many years, some major funding agencies have provided program and guideline information mostly through the web. They include the National Science Foundation (NSF), the U.S. Department of Defense, of Education, of Energy, and of Agriculture to name a few. The same is true for national and international foundations, including the Ford, Rockefeller, and McArthur foundations and the Carnegie Corporation of New York. It is difficult to find a college or university in the US without an elaborate and welcoming web site. Public and philanthropic organizations have no monopoly on the Internet. In fact, the growth of the websites of commercials entities, from multinational corporations to one-person operations, is significantly fueled by competition. As for publishing organizations, several are already at the paperless stage, i.e., manuscripts are submitted online and some journals exist only in electronic format (i.e., The New Journal of Physics; www.nsp.org). Further, some have constructed electronic archives to hold journal issues going as far back as 1950 or earlier. The web sites of the American Physical Society (www.aps.org) and of the American Institute of Physics (www.aip.org) provide illustrative examples that permit the online search (by topic, author, etc.) of leading, professional journals.

On the standard learning and teaching fronts, the awareness of highly useful materials, including entire courses, could be useful. Indeed, with the assistance of web-based instruction industries, many departments and individual professors have built significant online resources. In fact, in many universities, the delivery of several courses is partly or entirely through Blackboard, a leading web-based instructional material development and service delivery organization. The World Lecturer Hall (WLH, www.utexas.edu/world/lecture) has had extensive course materials online, sine the mid-1990, in most disciplines. The early materials were mostly for the undergraduate curriculum. Much progress is ongoing for graduate level courses. Many of the courses available at the World Lecture Hall (WLH) contain everything – including syllabus, detailed lecture notes with graphics, assignments, solutions to problems, etc. We should note that Plato was one of the earliest pioneers of computer assisted learning and is currently offering much service through the web, along with a growing number of competitors.

The point of the above paragraphs was not to describe fully what is currently available through the web for research, learning, and teaching. We doubt that any single book can provide such a description. We did not even mention cases where sophisticated experiments can be remotely performed via the web. The point of this introduction is therefore to underscore the need to be alert and to seek out proactively well-established websites that can support your work, now or decades from now.

Sound Judgment

The web is not accessible only to individuals or organizations, public or private, with accurate information. Hence, the proper use of the web requires the development and continued refinement of sound judgment. Some wise persons consider the World Wide Web to be a dream place with a growing number of land mines ready to explode should we step on them. We need not dwell on the need to avoid illicit and pornographic websites. For one thing, it is illegal to view them with most local, state, or federal computers or other resources.

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We do have to warn sternly against failing to apply APC^3 when seeking information through the web [1], i.e., to ensure the accuracy, precision, completeness, coherence and clarity (APC^3) of information before acting on it or being emotionally affected by it. The reader has to see Reference 1 for details. We recall that ensuring the accuracy demands verification through other independent sources. While many instructional materials from reputed faculty members and institutions are reasonably accurate, overgeneralization is not prudent. One reason for this situation is that lesson plans and research "findings" on the web, if not from refereed journals or sources, can be incorrect and, in some cases, patently false. As for advertisements on the web, for mundane products or nutritional supplements, some can be particularly misleading. The "get rich quickly" schemes are growing in number and sophistication. It is therefore one's responsibility to execute sound judgment for using the web effectively without harming oneself.

Utilizing the Internet for Competitiveness

A few utilizations of the web are rapidly becoming parts of a professional culture. Typical examples include (a) learning extensively about an organization and some personnel prior to an interview, (b) getting well acquainted with a department and some faculty members before joining them for graduate studies, (c) following funding opportunities, (d) searching the literature thoroughly, and (e) using search engines to find web information on most topics, groups, or entities. Without further details, we urge the reader to visit the World Lecture Hall or the sites of some colleges or universities to appreciate fully the extent to which the web is being woven into the fabric of teaching and learning. At least four (4) hours will be needed to have a non- superficial notion of the referenced weaving. What is even more is that it is just beginning!

It is the opinion of several national experts I consulted that research competitiveness requires a professional, consistent utilization of the web. The literature search that took 120 hours when I was writing my dissertation in the early 1980, took an average of three (3) hours in 2004. Indeed, the websites of APS, AIP, and of the Institute of Physics (IOP.org in the UK) permit the online search of tons of journals from periods ranging from 2004 to 1900! The free searches provide titles, authors, abstracts and options to access the selected articles. A subscription is generally needed for accessing full articles (for online reading or printing). An informed undergraduate or graduate student knows that departmental faculty members, the department, and the university library generally have online subscriptions!

Instead of focusing on searches in some specific journals, one may elect to utilize the online version of the Science Citation Index. Unlike the searches of specific journals, these searches practically cover the planetary literature (in many different languages) on the subject at hand. Other specialized databases exist and some are being developed. Again, a subscription, generally available through college libraries, is needed to access most databases. We should not, however, the trend toward free access to full articles. Clearly this trend, given the financial implications for publishers, will take time to spread. The New Journal of Physics (www.nsp.org) is one of the pioneers of this trend. It charges authors, most of whom have publication costs in their grant budgets, in order to offer the journal to the world, via the web, free of charge. The Institute of Physics (IOP) of the United Kingdom launched it in 1998-99.

In light of the preceding, all LS- LAMP and Timbuktu Academy Scholars are expected to utilize the web judiciously in their competitive learning and research activities.

[1] "The Law of Human Performance and Excellence in Research," D. Bagayoko, Proceedings, NAFEO High Tech Student Expo, pages 27-33, 2001. Printed in Baton Rouge, Louisiana (ISBN 0-9704609-3-7).

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SESSION: OPENNING PLENARY SESSION

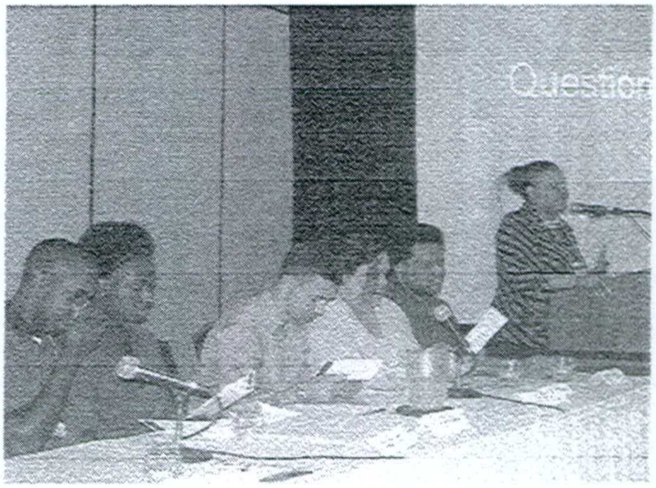
Calvin Mackie, Ph.D.
Tulane University

SESSION: COMPETITVE MENTORING: DEPLOYING THE MODEL OF A US PRESIDENTIAL AWARD FOR EXCELLENCE IN SCIENCE , MATHEMATICS, AND ENGINEERING MENTORING

Mentoring for Global Competitiveness

Diola Bagayoko, Ph.D. and Luria Stubblefield, Ph.D.
Southern University and A&M College
bagayoko@aol.com

"Mentoring is the general, pervasive, and ubiquitous process by which value systems, cultures, knowledge, and skills are transmitted from one generation to the next and within a generation [1]. " Increasing evidence shows that mentoring is an essential component of the competitive educational process, including the development and enhancement of research proficiency. The United States Presidential Award for Excellence in Science, Mathematics, and Engineering Mentoring (US-PAESMEM), from 1996 to present, has been recognizing outstanding mentoring efforts and results by both individuals and programs [2]. The proceedings [3] of the annual symposia held during the award ceremonies are very useful sources of models for successful mentoring. Other scholarly publications are beginning to recognize mentoring as a distinct area of inquiry.



The *Journal of Materials Science Education* [4], for illustration purposes, contains a comprehensive description of the Ten-Strand Systemic Mentoring Model of the Timbuktu Academy [5] at Southern University and A&M College at Baton Rouge SUBR), LA. The Academy won the US-PAESMEM in 2002 and its director won the individual award in the first year that the award was instituted, in 1996.

This article is mainly aimed at encouraging faculty, staff, and administrators to utilize the references noted herein and others in order to institute or to enhance systemic mentoring activities and programs. Bagayoko et al [1] provided operational definitions for both mentoring and systemic mentoring. In particular, to be systemic, mentoring has to (a) be integrated into the core activities of an organization or unit therein, (b) be supported financially and otherwise, and (c) be counted in the reward system of the organization.

A very important distinction of the Timbuktu Academy is its rigorously, scientific approach to systemic mentoring. In particular, it utilizes the power law of human performance (PLP) [6] and its extension, the integrated law of performance [7], to demonstrate how we can make a genius out of any child [6-9]. *Genius is mostly the result of sustained practice.* The same way adequate practice, at an adequate scope and depth, is needed to make sport champions, musicians, and artists, the same way it is needed to make science, mathematics, engineering, and technology (STEM) scholars. Further, the PLP shows how mentoring is the coupling between teaching and learning, on one hand, and between research and education on the other hand [9].

The institutions of the Louis Stokes Louisiana Alliance for Minority Participation (LS-LAMP) have adopted and adapted the model of the Academy to guide the successful implementation of LS-LAMP. Some salient developments at some LS-LAMP partner institutions are adding immensely to the prospect of its institutionalization. A few of these developments are: a) starting in 1997, the quarter-time release from teaching of a departmental mentoring coordinator in every STEM unit at SUBR; the establishment and the extensive work and results of the Office of the Vice Chancellor for Strategic Initiatives at Louisiana State University (LSU) at Baton Rouge, LA, with mentoring as a central strategic initiative; mentoring is woven throughout the new and forward looking strategic plan of LSU; the establishment of research requirements at Dillard University for earning a bachelor's degree; and the exemplary progress made by the Program for Excellence in Science, Mathematics, and Computer Technology (PESMACT) at Southern University at New Orleans (SUNO) in truly addressing pre-college to college transition in a fail-safe manner.

The results of LS-LAMP institutions naturally include first and foremost the growing numbers of minority earning BS degrees in STEM fields, and the increasing numbers of these alumni who attend and succeed in graduate school. Mentoring is the engine of these increases in the numbers and the quality of the minority BS degree holders. This point often escapes a casual observer due to the intricacies and subtleties of this pervasive factor in students' success. We should note that in the work of LS-LAMP, including the exemplary development cited above, institutional leadership was brought to bear. At the State level, the Louisiana Commissioner of Higher Education, Dr. J. Savoie, and the Deputy Commissioner for Sponsored Program, Dr. K. Davidson, continue to play statewide roles in enabling LS-LAMP. Naturally, we hope that the readers understand that systemic mentoring cannot be implemented without the essential work of the faculty with students. Our aim here is therefore to underscore to faculty members that excellent teaching, in a mentoring environment, is translated into competitive learning by the students. Similarly, excellent mentoring serves to integrate research and education. We should add that some of the students' research can and should be conducted off campus, at federal, industrial, and university sites around the country.

Mentoring provides an almost fail-safe strategy for promoting the academic excellence of all students (female or male, minority or non-minority, young or mature). The power law of performance as applied by the Academy and LS-LAMP actually provides the enabling principle for leaving no child behind. High student retention rates, on-time graduation, and the success of alumni in college or in graduate school are mostly by-products of the quest for excellence — through competitive teaching, *mentoring*, and learning. Even in the private sector, anecdotal evidence exists to suggest that mentoring is a tool for competitiveness, particularly for generations in the row.

Acknowledgments: The Timbuktu Academy is funded in part by the Department of the Navy, Office of Naval Research (ONR, Grant No. N00014-04-1-0587). LS-LAMP is funded in part by the National Science Foundation (NSF) and the Louisiana Board of Regents (Award No. HRD 0000272).

REFERENCES

1. "Fundamentals of Mentoring and Networking," D. Bagayoko, R. L. Ford, and E. L. Kelley, in "Scholarly Guidepost for Junior Faculty." Published by Quality Education for Minority (QEM) Network, Washington, DC, 2000.
2. http://www.ehr.nsf.gov/EHR/HRD/paesmem.asp, also see the web site partly devoted to US-Presidential Award recipients (individuals and programs), at the University of Kentucky (**http://www.uky.edu/RGS/Membrane/welcome.html**).
3. Annual Proceedings of the symposia held in conjunctio the US Presidential Award ceremonies, available fro National Science Foundation).
4. "Basic and Advanced Training for the New Millenniun model of the Timbuktu Academy," D. Bagayoko, R. E. L. Kelley, and S. Hasan, *Journal of Materials Edu* Vol. 24, Pages 177-184, 2002.
5. http://www.phys.subr.edu/timbuktu.htm.
6. "Mechanisms of Skill Acquisition," A. and P. S. Rosenb Edited by J. R. Anderson, Hillsdale, NJ: Erlbaum, 19
7. "The Dynamics of Student Retention," D. Bagayoko and Kelley, *Education* Vol. 115, No.1, 31-39 (Fall, 1994).
8. *"Closing Academic Achievement Gaps."* D. Baga Challenge, Vol. 13, No. 1, Fall 2002.
9. *"The Philosophical Foundations of Systemic Mentoring Timbuktu Academy."* D. Bagayoko. Science Next American Association for the Advancement of Sc (AAAS). An online publication available at **ht nextwave.sciencemag.org/**, 2002.

SESSION: THE PATHS OF SCIENCE: WHERE SCIE AND TECHNOLOGY-BASED EDUCATION CAN LEAD

The Paths of Science: Where Science- and Technology- Education Can Lead

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http://microEP.uark.edu

The Paths of Science:
Where Science- and Technology-Based Education Can

- Critical items for career success
- So you want to be a graduate student...
- microEP – an illustrative example
- Acknowledgements (truth in advertising)
- Questions (at the end of the presentations)

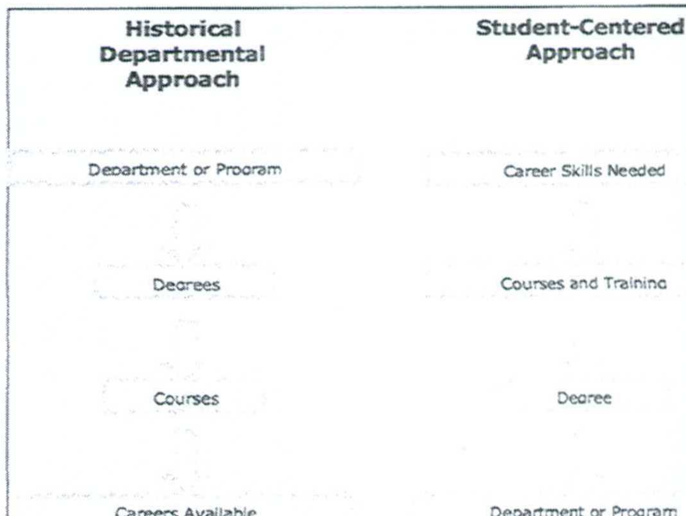
Career Success in Science and Technology: Key Issu

"Time required for degree preparation ironically *doe allow students the chance to develop skills* for effective communications and knowledge of culture, law, econo and ability to maneuver in a global workplace - ALL p engineering practice."

"While further training in technical matters and mark issues occurs on the job, *any depth in non-tech knowledge and skills must be acquired off-the-record."*

Kunda, 1992; Bucciarelli and Kuhn, 1997 (emphasis a

We respectfully disagree...



Vol. 13, No.1 / Fall 2002

CLEMSON
UNIVERSITY

Challenge

The Houston Center for the Study of the Black Experience Affecting Higher Education

Closing Academic Achievement Gaps

by Dr. Diola Bagayoko

Diola Bagayoko

Academic achievement gaps are the differences that exist between the average scores of various groups of students on some standardized tests. These groups include those characterized by the gender, ethnicity, socioeconomic background, or the educational level of the parents of the students. The standardized tests may be national or local. They include tests of the National Assessment of Educational Progress (NAEP), administered by the US Department of Education, the Scholastic Assessment Test (SAT), and the American College Test (ACT).

Over the years, journal articles, newspaper accounts, and books have attempted to explain these gaps between groups of students on the basis of attributes believed to be inherently related to characteristics like ethnicity or gender. Some sources mistakenly took correlation to mean causation while the two generally have nothing to do with one another. It appears that the complexity of the educational process and the persistence of some of these gaps overwhelmed writers and speakers as well as readers and listeners dealing with these gaps. Or so it seems to us.

Some colleagues and I have taken a rigorous, scientific approach to understanding the real origin of these gaps. Using the well-established Law of Human Performance (Ref. 1), we first explained thoroughly the differences between the achievements of individuals in sports and in the arts. Unquestionably, regardless of gender, ethnicity, socioeconomic status or other characteristics, most of the differences between individual or average group achievements in these arenas were traced to the extent to which the concerned parties were adequately exposed to the relevant sport or artistic tasks and the degree to which they actually practiced them! We also verified that in all countries and cultures known to us, this explanation is understood.

We then turned to the search for a scientific explanation of the achievement gaps defined above. We found that they are always made, like differences in sports and the arts, by differences in exposure, practice, and efforts! Indeed, we established that there was not one case of academic achievement gap that was not explained by one or more of the following ABCs of

continued on page 2

Adopting Technology to Transform the Learning Environment

by Kageni Njagi

Rapid growth in information technology and instructional technology has revolutionized learning both inside the classroom and in the area of distance education. Higher education is becoming increasingly reliant on technology to deliver learning. There has been a major shift from the traditional methods of teaching to creation of high technology learning environments in the last ten years. Instructors are now using technology to support their teaching efforts while students on the other hand are benefiting from the diverse learning resources available. Why is technology gaining so much popularity in the learning front and what is influencing its adoption?

While technology must not be viewed as a means to an end, it must be seen as a tool to assist in making learning more meaningful. Well-implemented instructional technology programs have the capability to engage learners and create excitement in the learning process; and can be powerful tools for improving the motivations and incentives for learning (Garmer & Firestone, 1996).
A technologically enriched classroom environment also has a positive influence on student's use of higher order thinking skills such as problem solving, reasoning, and reflection (Hopson, Simms & Knezek, 2001-2002). Since the workplace is looking for dependable employees who are capable of working with little or no supervision, students must be empowered to

continued on page 2

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Academic Achievement Gaps

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learning or training: (a) the appropriateness, relevance, and competitiveness of the curriculum (subject contents and skills) at every grade level, (b) the adequacy of the scope and depth of the exposure to this curriculum in its entirety as enabled by standard-based teaching, and (c) the actual amount of time a student spends learning, applying, and practicing said contents and skills—in and outside the classroom. "Appropriate" and "adequate" are objectively defined by competitive standards and not some parochial or self-serving norms or criteria set by someone.

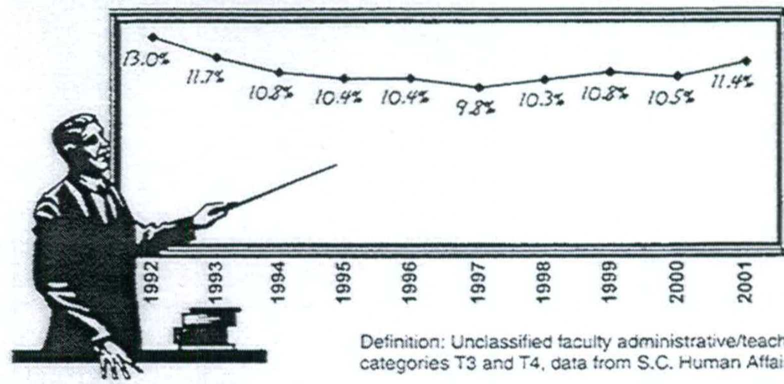
The above scientific explanation says that socioeconomic status, ethnicity, and gender, etc., are not intrinsic factors that determine the academic achievement levels of students! Their effects, if any, are indirect and can be avoided if the ABCs of training are followed rigorously. Indeed, socio-cultural conditioning for gender and ethnicity, including peer influence, low expectations, lack of resources, poor schools, etc., can thwart the application of the ABCs of learning. Issues are further complicated by the cumulative nature of learning because inadequate reading or a lack of mastery of algebra I (or at least pre-algebra) by the third grade and eighth grades, respectively, lead to low achievements in high school and beyond.

(Ref. 1) Upon request, the author will email or mail to interested readers journal articles on the Law of Performance as well as selected documents and national data verifying the above explanation of the making of the academic achievement gaps.

Dr. Diola Bagayoko is SU System Distinguished Professor of Physics and Director of the Timbuktu Academy, Southern University and A&M College, P. O. Box 11776, Baton Rouge, Louisiana 70813 (Bagayoko@aol.com)

Challenge Stats

Percentage Black Faculty at S.C. Technical Colleges: 1992–2001



Definition: Unclassified faculty administrative/teaching staff, categories T3 and T4, data from S.C. Human Affairs Commissio

Adopting Technology

continued from page 1

participate in life-long learning practices in order to compete in the changing learning and work environments. If students learn to learn, the society will benefit from a better-informed, more knowledgeable citizen who is transformed to a skilled, productive, competitive and marketable worker for the global market.

Although technology has the ability to change and even create high-powered learning environments, traditional methods of delivery still persist in some classrooms. Resistance to change toward technology integration may be attributed to deeply embedded beliefs in the prevailing institutional culture. Individual instructors may also respond to internal barriers like fear of the unknown and lack of experience with computers. There are no quick fixes to culture issues, but exposure can erase some of the fears within the users. Other barriers to technology integration are basically administrative in nature and depend on the attitude of the policy makers to learning technology.

The long-term impact of technology in higher education will be the result of concerted efforts by all stakeholders in the education front. Administrators, policy makers and instructors must be willing to take risks and face challenges in order to make the learning environment more productive and meaningful. It is the administration's responsibility to put in place the hardware, software, and needed networks, which would make the integration of technology a reality in higher education. To erase fears fo the unknown, instructors should take advantage of workshops organized to orient and train faculty ar staff on the process of implementing technology successfully.

Kageni Njagi

The rapid growth in technology has dramatically changed the way we live, work and learn. Today's educators must be concerned with how to use technology to enhance and enrich their learning environments. Adaptation of technology opens up a variety of advantages t both the learner and the instructo. If technology is helping build motivation among the learners while addressing a variety of learning styles, and is creating flexibility in the learning process, then instructors should be asking how and wh technology will enrich their classrooms.

Kageni Njagi is a graduate student in the department of Career and Technology Edu cation and graduate assistant in the Hous ton Center.

Testy about testing? Let's Partner for Student Success

by Dr. Debra A. King-Johnson

After giving a great deal of thought to the Palmetto Academic Challenge Test (PACT) and how the tests/scores relate to minorities, I decided to visit a local school for more information. At Northside Elementary School in Seneca, South Carolina, I met with Principal Geoff Smith. Our discussions revealed that the PACT is our state's way of addressing concerns about academic excellence and outcomes for students. In view of the importance placed on such testing, I thought it best to discuss the "whys and hows" of testing and performance.

Purpose of tests. Testing in general has many purposes. Tests are meant as tools to assist educators. They are to assess ability, provide information on students' gains, make predictions about performance, identify skill deficits, and pinpoint areas for remediation and academic concentration. Tests are a measure of student responses on a set day and given certain circumstances.

Performance of minorities on tests. Traditionally, minorities have performed less well on tests. This may be attributed to their tendency to take a creative view to problem solving. When solving problems to get the correct answer, test takers must stick to very logical rules of elimination and information processing. Standardized tests do not reward creative skills since using such information does not aid correct answers.

Misuse of tests. Tests and test scores are often misused when they are not interpreted properly, when untrained persons are interpreting them, or when they are used to exclude certain groups. Misuse of testing may occur when certain tests are the sole sources of information instead of being part of a battery to provide information about someone. Tests that do not have positive outcomes such as incorrect placement for a student or test results that are used to make direct statements of causes for variation in academic performance, and failure to inform parents before, during and after the testing process are other ways testing may be misused. There is a relationship between students' performance and the instruction they receive, but it is poor science to say that instruction causes test performance.

Role of parents. Parents are to provide support for the efforts of the school: education and learning are priorities. Parents need to help children/students become productive members of society, enhance the confidence of their children, and help their children understand that the information they are learning will be used at some point in their lives. By seeking to partner with the school, parents can incorporate success strategies early in the school career of their children.

Role of teachers. As professional educators, we should facilitate and guide students in gaining information. We must never assume the role of the one who ensures that this happens. Using an age appropriate developmental model for presenting material, we as teachers must help students help themselves. This involves teaching test-taking skills in addition to knowledge and information. We must impress upon students the concept of lifelong learning. Each year the students have a new teacher but they remain the constant. Their role is the most significant in the partnership.

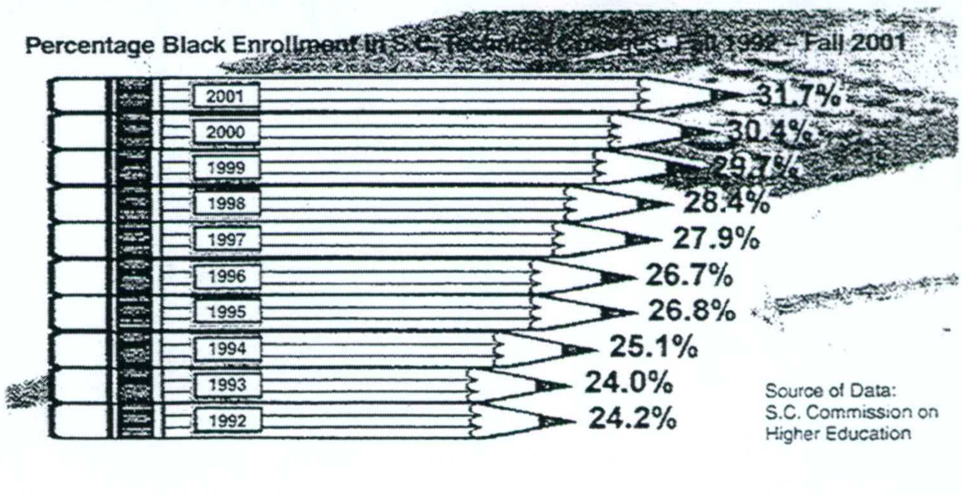
Debra A. King-Johnson

Role of students. Students are to be sponge-like, soaking in then giving back what has been presented to them. They must stay motivated, show interest, take responsibility and ownership of their learning. Self-direction is the students' responsibility, which enables them to internalize the significance of certain skills in order to achieve success and maximize performance. This allows them to mature, set goals to reach, strive and to see the bigger picture.

Conclusion. I support the use of tests when done properly and with consideration for the true role testing should have in the overall plan for academic success.

Dr. Debra A. King-Johnson is a licensed professional counselor/supervisor in private practice: Family C.A.R.E. Services. She is an adjunct professor at Tri County Technical College and Southern Wesleyan University where she teaches psychology courses.

Challenge Stats



Source of Data:
S.C. Commission on Higher Education

CALL FOR PROPOSALS

The Center for the Study of Black Experience Affecting Higher Education is accepting proposals for Fall 2002 grant awards.

Proposals must be received in our office on or before December 12, 2002. Grants will be awarded February 12, 2003. Higher priority will be given to proposals that study issues related to access, retention, and quality of life for black students in South Carolina higher education.

Proposals should not exceed five pages and should include a statement of the problem, planned methodology, a line item budget, and the time frame in which the study will be conducted. Attach one biographical sketch of the principal investigator and a bibliography.

The maximum amount of any grant is $1,000. Persons at public and private colleges and universities are encouraged to submit proposals. For further information, contact the Houston Center at (864-656-0313).

Highlights in Black History

1787, July 13 - The Continental Congress passed the Northwest Ordinance which provided for a government and civil liberties for the new territory and excluded slavery northwest of the Ohio River except as punishment for a crime.

Source: Munirah Archives, St. John's University

1862, September 22 - The Emancipation Proclamation was announced.

1895, September 18 - Booker T. Washington delivered his famous Atlanta Exposition speech.

1910, September 29 - The National Urban League was founded in New York City.

1921, September 14 - Constance Baker Motley, the first African American appointed to a federal judgeship, was born

1992, September 12 - Dr. Mae C. Jemison became the first African-American woman to travel in space.

Source: TheBlackMarket.com

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This newsletter serves as a forum for ideas having to do with minorities in higher education. Comments an suggestions from readers are welcome as are papers and articles to be considered for publication.

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* Excerpt from the *Fifth Annual DoE EPSCoR and LS-LAMP Research Conference Proceedings 2001* (ISBN 0-9704609-4-5), pages 52-54.

Session Presentations

Traveling as far away as New York City, the students also participated in conference discussions on the use of LabWorks technology, financing graduate education, and succeeding in graduate school. Sessions like "Reinvigorating your Research Program through Collaborations," "Undergraduate Research as a Vehicle for Success for Underrepresented Students in Science and Engineering," and the "Role of Undergraduate Research in the Recruitment/Retention of Students" provided information and resources on improving undergraduate research in two-year and four-year colleges and universities. The following pages are presentations made during the conference as submitted by the speaker for these proceedings.

Avoiding (or Closing) Academic Achievement Gaps

Diola Bagayoko, Ph.D.
SU System Distinguished Professor of Physics
Director, Timbuktu Academy and PIPELINES
Co-Investigator, Louis Stokes Louisiana Alliance for Minority Participation

The Power Law and the Law of Performance:
A Rosetta Stone for Deciphering the Process of Education

Recent articles in the Baton Rouge *Advocate* (http://www.theadvocate.com) addressed the achievement levels of students on the American College Test (ACT) and other standardized examinations. Please see "Test score gap offers challenge" (the Advocate, 10/02/00, page 1A), "Suburban parishes ACT scores mixed" (*Advocate*, 8/29/00, page 1B), "Reading, science scores static in national tests: gap grows between black, white students" (*Advocate*, 8/25/00, page 1A), and "1999 ACT scores of area schools" (*Advocate*, 2/29/00).

In light of the enduring interest reflected in these articles and many others, we presume that the public is interested in a complete explanation of "what determines achievement levels on tests." Specifically, two publications explained, using the power law of human performance also known as the power law of practice, how achievement levels are reached [See *Education*, Vol. 115, No. 1, pp. 31-39, 1994 and pp. 11-18].

The first of these publications provides an extension of the power law known as the compound law or simply the law of practice (CLP or LP). This law clearly, unambiguously, and implacably shows that the achievement level of a student on a standardized test is directly determined, first and foremost, by (a) the exposure of that student to appropriate subject contents and skills, (b) the adequacy of the scope and depth of this exposure, and (c) the actual amount of time the student spends learning, applying, and practicing said contents and skills—*in and outside the classroom. "Appropriate" and "adequate" are objectively defined by competitive standards and not some parochial or self-serving norms or criteria set by some individuals.*

According to the law, socioeconomic status, ethnicity, and gender, among others, are not intrinsic factors that determine the achievement levels of students! *Their effects are indirect. Academic achievement levels depend first and foremost upon access to and utilization of competitively engaging, standard-based education and in-*

directly upon socioeconomic and cultural conditions. Negative, indirect effects of socioeconomic, ethnic, and gender factors on academic achievements, if any, can be avoided by ensuring items (a) through (c) as noted above.

The power law of practice (or of performance) and its explanation of the achievement levels of students are presented in detail in a video tape, *Genesis of Genius,* available from the Louis Stokes Louisiana Alliance for Minority Participation (LS-LAMP) at Southern University and A&M College, Baton Rouge [http://www.ls-lamp.org, telephone: (225) 771-2777.

Interestingly, most individuals are familiar with the necessity for items (a) through (c) in sports and the arts. It is the same for intellectual endeavors! We hope that interested parents, teachers, students, and others will take advantage of this video tape that also explains how achievement gaps between various groups of students, on standardized tests, are formed. *These gaps, according to the LP, can be avoided or closed by the application of items (a) through (c) listed above.* The Timbuktu Academy has been doing so since 1990 (http://www.phys.subr.edu/timbuktu.htm)! The rigorous application of the above law allows the Academy to register quantum leaps in the ACT scores of its pre-college, summer students every year. Details on these leaps are available at the web site of the Academy and upon request. In each of 2000 and 2001, 10 of these pre-college scholars of the Academy were among the National Achievement and National Merit semifinalists!

Explaining American College Test (ACT) Scores of U.S. High School Graduating Class of 1999 (Similar results are found from 1996 to 1999, with slightly changing gaps)

The law of performance (LP) explains academic achievement gaps. Note the smaller mathematics gap (mathematics) that widens with course taking! The key (i.e., Rosetta Stone) to the puzzle is that the scores, as per the LP, are determined (causally so) by the actual learning (practice)—mediated in part by (a) course taking, (b) the topics, their scope, and depth in every course, (c) the actual practice by the students as mediated (or induced) by graded homework assignments, tests, and others. *All algebra courses are not equal or equivalent; and, all students taking given courses do not devote equivalent times to these courses; the needed time for a course, incidentally, depends on the background of a given student!* Therein lies the quintessential source of differences between the achievement levels of students who took similar courses. Course taking alone, as shown in the table below, accounts for most of the rest of differences between the achievement levels of students. Genes, intelligence quotient (IQ), ethnicity, and gender do not enter into this explanation or equation.

Note the large gap, in English, for those taking less than four years of English. It is partly at the root of the large gaps, of similar sizes, in reading and in science reasoning! See exposure (at home, school, etc.) to Standard English and a rich vocabulary environment, from birth to the test date, to explain the gap in English—as per the law of performance or of practice.

Noting how the English gap contributes to the gaps in others, the Timbuktu Academy doubled the time devoted to English by its summer pre-college students in 1996-97. Following this change, ACT score improvements, over a six-week period, jumped from an average of two to an average of four or five. The strong and positive correlation between the SAT and the GRE scores in the verbal and quantitative sections, respectively, gave the Timbuktu Academy an added incentive to close the English gap. As expected, the gaps in reading and science reasoning narrowed significantly. After all, languages are the vehicles of thought. See Table I.

For the Creation of Educational Value-Added (i.e., High Academic Achievements)

(1) The law of performance says that all students can learn—at a competiti[ve] level. It is the scientific basis for high expectations for all students! It also says th[at] exposure to competitive curricula, over the years, and adequate learning a[nd] practice are necessary for high academic achievements by most students.
(2) The law of performance also says that exposure to substandard curricu[la], over the years, will ineluctably result in low achievements, irrespective [of] intellectual quotient, genes, ethnicity, gender, etc. Whatever the reason[s], tracking a student in "low ability" groups guarantees that said student will u[n]derachieve.

(3) There is no substitute for standard-based subject matter and skills content [in] each and every course, from pre-K to graduate school and beyond.

(4) There is no substitute for the adequacy of the battery of courses taken [at] every grade level. A national, reference curriculum, from K through colleg[e], will inform parents and students of prevailing competitive norms or standards.

(5) There is no way to circumvent the *internal rigidity* (i.e., sequential nature [of] aspects of knowledge). Consequently, the knowledge and skills base of th[e] learner has a great influence on the "acquired ability" to learn. Particula[r] difficulties in many courses are often due to utterly inadequate background a[s] opposed to a lack of "smartness." Writing follows reading. Calculus follow[s] arithmetic, algebra, and basic geometry and trigonometry.

(6) There is no substitute for the devotion of "adequate" time to learning tasks. So says the law of performance (LP). "Adequate" is to be determined usin[g] competitiveness criteria and national norms and standards. In the absence [of] a reference curriculum, those with the least intellectual, material, and financia[l] means are likely to have the most difficulty in the determination of a competitiv[e] curriculum and of the "adequacy" of the time on learning tasks. This holds fo[r] parents, teachers, and students.

(7) There is no substitute for quality teaching, with its inherently closed feed[-]back loop. Such a teaching commands a significant portion of the out-of-class time through graded assignments. These assignments simulate the actual way in which knowledge is applied and research is conducted. They do so bette[r] than any test, however comprehensive it may be. Further, they mold study habits over time; these habits are critical aspects of the unwritten curriculum.

(8) There is no substitute for parents or guardians in ensuring that adequate time is spent on learning tasks during the academic year and in the summe[r] (i.e., reading and report writing). Consequently, they have to limit TV viewing, video playing, and listening to music. These activities and similar ones are privileges that should be earned by young students after doing school work.

(9) There is no substitute for familiarity with the format and subject/skill content o[f] applicable tests. This tautology applies to all standardized tests, whether they are norm- or criterion-referenced, from kindergarten through the doctoral degree.

(10) There is no substitute for efforts and practice in acquiring and enhancing proficiency in a complex process, from reading to writing, research, and problem-solving, sports, and the arts. So says the law of performance, regardless of claims of "innate" abilities.

TABLE I

A comparison of the ACT scores of African American/Black and of Caucasian/White students for the graduating class of 1999. Similar results for the gaps, due to course taking and to the actual time on learning tasks of varying standards, are found for 1996 through 1998, with slightly changing gaps. In the table, E stands for English, A for Algebra, Trig. for Trigonometry, Geom. forGeometry, Hist. for History, Phys. for Physics, Chem. for chemistry.

English Course Pattern	Number of Black Students	ACT English	Number of White Students	ACT English	GAPS
E9, E10, E11, E12, Speech	24,586	**17.0**	250,463	**21.8**	**4.8**
E9, E10, E11, E12	69,780	16.4	422,673	21.3	
Less Than 4 years of English	5,940	**14.8**	38,515	**19.4**	**4.6**
Course Taking Difference (top-bottom)		*2.2*		*2.4*	
Mathematics Course Pattern	**Number of Black Students**	**ACT Math**	**Number of White Students**	**ACT Math**	**GAPS**
A 1, A 2, Geom., Trig., Calculus	4,022	**19.7**	46,643	**25.1**	**5.6**
A 1, A 2, Geom., Trig., other Advanced Mathematics	7,085	18.9	75,979	22.6	
Other comb. Of four or more years of Math (i.e., Mathematics)	18,538	19.0	170,873	24.6	
A 1, A 2, Geom., Trig.	10,442	17.3	75,307	21.1	
A 1, A 2, Geom., other Adv. Math	9,518	17.4	83,605	20.9	
Other comb. Of three or 3.5 years of Math	6,181	16.6	37,278	20.5	
A 1, A 2, Geom.	28,288	15.6	144,952	18.2	
Less Than 3 years of math	15,967	**14.8**	75,208	**16.8**	**2.0**
Course Taking Difference (top-bottom)		*4.9*		*8.3*	
Social Science Course Pattern	**Number of Black Students**	**ACT Reading**	**Number of White Students**	**ACT Reading**	**GAPS**
US Hist., World Hist., American Government, other History	2,522	**17.8**	21,612	**22.8**	**5.0**
Less than 3 years of Social Science	17,899	**16.2**	104,682	**21.1**	**4.9**
Course Taking difference (top-bottom)		*1.6*		*1.7*	
Natural Science Course Pattern	**Number of Black Students**	**ACT Science Reasoning**	**Number of White Students**	**ACT Science Reasoning**	**GAPS**
Gen. Science, Biology, Chem., Phys.	26,733	**18.4**	224,723	**23.2**	**4.8**
Less Than 3 years of Natural Science	24,921	**16.1**	152,562	**19.5**	**3.4**
Course Taking Difference (top-bottom)		*2.3*			*3.7*

SOURCE: *ACT Research Services, P. O. Box 168, Iowa City, Iowa 52243. Telephone: (319) 337-1113; Fax: (319) 339-3020. Courtesy of Merine Farmer and ACT. For the Creation of Educational Value-Added (i.e., High Academic Achievements)*

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THE LAW OF PERFORMANCE AND EXCELLENCE IN RESEARCH

A Comprehensive, Precise, Dynamic, and Quintessential Guide to Successful Careers in Science, Mathematics, Engineering, and Technology (SMET) Fields and Others

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Acknowledgments. The research and related work that led to most of the findings in this paper were funded in part by **(a)** the Department of the Navy, Office of Naval Research (ONR, Grant No. N00014-98-0748), through the Timbuktu Academy; **(b)** the National Science Foundation (NSF), through LS-LAMP (Award No. HRD-0000272); and **(c)** the National Aeronautics and Space Administration (NASA), through the Program to Increase the Pursuit of Education and Learning IN Engineering and Science (PIPELINES, NASA Award Nos. NAG5-8552 and NCC13-00010). **(d)** The presentation of these findings in a keynote address at the 2001 NAFEO High Tech Student Expo was funded by the National Science Foundation, through a supplement (Award No. HRD-0000272, Amendment No. 001) to LS-LAMP. The noted funding notwithstanding, the author bears the entire responsibility for the content of this article and of the related presentation.

ABSTRACT

"Luck is what happens when preparation meets or makes, recognizes, and acts on opportunity." This paper first identifies essential attributes (knowledge, skills, experience, behavioral traits) that undergird successful careers in SMET and other fields. It then presents the Power Law of Performance and the Law of Performance that assert that any individual not suffering from a severe physiological or mental impairment can excel in any discipline of study, including SMET fields, and can secure successful and rewarding research-based careers. *Devoting adequate time to learning and to the practice of research, according to the Law of Performance or of Practice (LP), is the a condition that applies to every individual—irrespective of "perceived" notions of "innate" abilities.* Using meta-thinking, we attempt to warn the reader about common errors and misconceptions related to careers, in general, and the ones in SMET, in particular. Specifically, the dynamic or ever-changing nature of work, market, and related environments is a fundamental reason for acquiring the versatility bestowed by research performance and skills. In the context of changes that are becoming faster, due to developments in SMET, research proficiency is both a warranty for continued employment, by virtue of its versatility, and of happiness, due to its many reward$ that include money and very much more. *Hence, beginning immediately and continuing to prepare oneself is the key to excellence.*

INTRODUCTION

While we have no need or intention to sound pretentious, we are compelled to warn the reader that no less than total concentration and the harnessing of most intellectual attributes are needed to appreciate fully what follows. Given the complexity of the issues, we had to utilize universal and powerful principles to address the topic in a comprehensive fashion. We did so by avoiding minutia that change with time and by focusing on overarching principles, trends, and patterns that are germane to the dynamics of human activities—from antiquity to the present and beyond. The size of this paper dictates that the reader be referred to current and future sources that delve into the details of careers in many professions. A second reason for this referral stems from the fact that these details change continually. The "smart" approach, in such instances, is to get the permanent sources of information as opposed to a specific piece of information that may be obsolete in a year or less [1]. The rest of this article follows the order intimated in the abstract.

THE "IMPERATIVES" FOR A SUCCESSFUL CAREER (IN RESEARCH IN SMET)

Language and Communication Skills

A detailed analysis of the tasks a person performs at most jobs reveals the following: **(a)** the need to read and to understand information from a variety of sources, including written and oral sources, diagrams, videos, etc.; **(b)** the need to transmit information to others in a flawless fashion—this perfect transmission requires that the information possess the following qualities: *accuracy, precision, completeness, coherence, and clarity (i.e., $APC^{3)}$*; the volume of information to transmit and the need for continuity often dictate that a flawless transmission include *written materials*; **(c)** the fact that learning is cumulative and that the more one knows about a subject or task, the better and faster one can learn additional, related materials, topics, processes, or instruments; and **(d)** the fact that thinking, after all, is done in a language.

In the case of a research careers in competitive sectors (public or private), having enough knowledge and experience to read and understand the literature and being able to write articles that pass peer or departmental reviews are simply non-negotiable. Further, the continual changes noted above require, to avoid obsolescence, that one follow new developments in *a regular fashion*—through professional magazines (i.e., Science, Nature), journals, web sites, books, and conferences. To do so, however, demands **competitive language and communication skills (i.e., reading, writing, listening, and speaking).** These skills, that are acquired and enhanced through practice, constitute the first "imperative" for a successful career. The implication of this everlasting reality is that there is no substitute for the mastery of the applicable language and of the utilization of the key qualities of information (i.e., APC^3). This mastery has to include that of the grammar, vocabulary, syntax, etc. in that language—as verified by standardized tests as opposed to self-misleading perceptions of mastery [see American College Test (ACT), the Graduate Record Examination (GRE), and other tests]. *Consequently, from pre-K to the Ph.D. and beyond, very well informed individuals regularly and consistently work to hone their language and communication skills. (Well, parents have to ensure the regular and consistent learning up to middle school, in many cases.)*

Homework: As all good professors, the only way we can verify that learning occurred is to close the feedback loop. So, the homework to be done for the above chapter on "competitive language and communication skills" is the following. Conduct three or more interviews of *successful* researchers and professionals (government, academia, or in industry). Design and ask ten (10) or more questions aimed a determining the extent to which language and communication skills play a role in their work. Hint: Do they get information from others? Do they transmit information to others? Do they write proposals? Do they have to follow guidelines or procedure manuals? Do they write strategic or other plans? Do they write reports or any kind? Do they conduct reviews (that require extensive reading)? Do they publish? Do they receive or send letters, memoranda, or electronic mails? Without APC^3, how do they avoid misunderstandings of all kinds—particularly when vital or critical issues are at $take? To what extent have their communication skills (i.e., language and APC3) contributed to their advancement or promotion? How could they function successfully *without* the communication tasks noted above? Please note, in these web and e-mail days, that many of these interviews could be conducted at a distance!

Mathematics (the language of Science and Technology)

Numbers and mathematics, believe it or not, have been inextricably woven into the fabric of human activities from the dawn of humanity to present. Further, scientific and technological developments that partly rest on mathematics are rendering the master of some mathematics an inescapable condition for successfully fitting into current and particularly future societies. This assertion could be substantiated, at an elementary level, by looking around oneself. What do you see, hear, or feel that can be totally characterized without using mass (numbers), shape (numbers and geometry), volume (numbers and geometry), or intensity (as of light or of sound, numbers)? At the intermediate level, motions of all kinds require numbers and mathematics for a complete description. It will require more than one book to describe the mathematics that went into the design and production of tools of all genres [i.e., kitchen appliances, pieces of equipments in hospitals, cars, airplanes, computers, sophisticated software products performing formidable operations, etc.]. **The ubiquity of mathematics is the reason it is the second "imperative" for a successful career (and for simply fitting functionally into present and future societies).**

The direct and obvious consequence of the above status of mathematics is that from pre-K to the Ph.D. and beyond, well-informed individuals work regularly and persistently to acquire, maintain, and enhance their mastery of mathematics. This mastery, as in the case of language and communication skills, is to be determined by objective measures and not delusional perceptions or ideas of mastery. Be kind and inform your younger relatives and your descendants that a solid mathematics course (or more) should be taken every year of high school—up to calculus, at a minimum. Inform parents you know that Algebra I should be taken in the 8th grade, at the latest. In college, the calculus series is a necessity, from calculus I to III. (Pre-calculus courses may need to be taken, before the first college calculus, if the high school mathematics was not adequate; before this paper, it is presumed that many people, unfortunately, did not know the utter seriousness with which mathematics has to be taken at all grade levels.) SMET undergraduate students should generally take, in addition to the calculus series, differential equation. Physics majors should add complex variables, vector calculus, and college level linear algebra. We provide below the general way of determining the needed mathematics courses for any major.

Mathematics is the language of science and technology, period, understanding it or not. Unfortunately, one has to know a great deal of science and technology to know appropriately the extent to which this assertion is true. So, a student is generally at a loss as to what mathematics

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courses to take and in what sequence—given that she/he does not know enough to know. The simple solution to this conundrum is to consult seriously (not in passing) with successful faculty members, researchers, engineers, technologists, medical doctors, etc. while one if far away from their level. (We advise doing it in the freshman or sophomore years if possible.) A synthesis of the responses from these professionals as to what mathematics courses to take and in what order will provide a clear road map. The reason this is critical rests in part on the fact that knowledge is often sequential or taxonomic in mathematics, i.e., Algebra I is needed before Algebra II, irrespective of one's "innate" abilities. *(Remember that no "innate abilities" guarantee championship titles in the Olympics, the National Basket Ball Association (NBA), the National Football Association (NFL), tennis, golf, etc., without extensive and sustained practice over time. Similarly, it takes studying, reviews, practice to excel in intellectual endeavors—so says the law of performance discussed below!)* Oh, some people do not understand that most difficulties in a mathematics class, *for someone who is studying appropriately*, are due to an inadequate background and not to any lack of innate "smartness" as explained below with the law of performance.

Fundamentals of Probability and Statistics

Our third "imperative" is "fundamentals of probability and statistics," a part of mathematics. While space limitation does not allow us to provide details on this affirmation, its importance is the reason it is addressed here by itself. This importance includes system failure issues in engineering, the plethora of probability and statistical systems in physics, and the inescapable presence of probability and statistics in dealing with large numbers of anything (people, electrons, atoms and molecules, nuclei and their decay processes, the parts in a complex system, etc.). Understanding that statistical correlations have nothing to do with causation, in general, may save one from falling under the spell of false claims by ill-informed sources. The complexity of issues in science, technology, and in society makes it patently necessary that a leader, lawyer, scientist, engineer, well-meaning politician, etc., understand the fundamentals of probability and statistics in order to avoid doing the opposite of what she/he meant! The June 15 Issue of Science reads in part, on page 1971 [2], *"statistics have become indispensable to scientists in almost every discipline."*

If you find the little book entitled "How to use and misuse statistics," or a similar one, you will have illustrations of the above point. The overall need for "probability and statistics" and the *need for it in most graduate programs in SMET demand that one take at least an introductory course in "probability and statistics" before completing the Bachelor's degree program.* In some SMET departments, the above introduction is provided in some courses (i.e., Statistics and Thermodynamics, in the case of some Physics departments). The online textbook by David Lane of Rice University [2] is an ideal self-help tool for an introduction to the basics of statistics. The online, interactive demonstrations of key concepts are noted by Science as a distinction of this new resource that was developed in part with funding from the National Science Foundation (NSF).

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Research Proficiency: Ultimate Versatility, Life-long Employment Warranty, Etc.

The process of creating new knowledge, i.e., research, is a very complex one. To begin with, it generally demands "competitive language and communication skills" that partly enable life long learning. In SMET, it also demands the mastery of some fundamental mathematics: the scope and depth of the needed mathematics vary with SMET fields, the experimental or theoretical nature of the work, and other factors. Please recall that without some serious mathematics, one cannot even read many publications in SMET let alone add to them.

Research proficiency or expertise includes knowledge, comprehension, application, analysis, synthesis, and evaluation. These six intellectual attributes are known as categories of the Bloom taxonomy of the cognitive domain. As noted above, research proficiency demands "competitive language and communication skills" and "adequate knowledge and skills in some areas of mathematics"—particularly in the case of SMET fields. The performance of research in SMET often follows *the scientific method* that can be written in a variety of ways. Our succinct rendition follows: (1) observations and note taking in accord with APC^3; (2) search for explanations in the scientific literature and note taking according to APC^3; (3) design of experiment or construction of a theory—accompanied with written notes that follow APC^3; (4) conduct of experiments or applications of a new theory—with detailed notes obeying APC^3; (5) analysis of findings (from experiment or theory) and comparison with observations and established, theoretical or experimental knowledge—documented in writing that obeys APC^3; (6) writing report and publishing findings—while paying special attention to accuracy, precision, completeness, coherence, and clarity (APC^3) for every proposition or statement; (7) in case of problems in a step (or if the comparison in step 5 does not lead to agreements), then go back to (1), (2), (3), or (4) to (a) look for possible oversights or errors or (b) formulate a new hypothesis, design a new experiment, or to construct a new theory. It must be clearly understood that while high school and other discussions of the scientific method do not generally include the extensive, detailed, and complete writing according to APC^3, this writing is the hallmark of an understanding of the actual scientific process or method. Laboratory journals or research journals or notes, the latter for theoreticians, are indispensable in the actual practice of research. (Let the hypocentral need for *accurate, precise, complete, coherent, and clear notes* be another reminder of the indispensable role of "language and communication skills" in SMET and in most intellectual endeavors.)

Once the research questions are posed, most research can be thought of a "problem-solving"! Indeed, the only difference may be that some research problems may require months or years to solve completely while some mundane or classroom problems can be solved rapidly. Essentially, however, research is just a form of problem-solving. Some of the researchers we admire the most, besides the ones in SMET, include law enforcement and forensic professionals. For the latter groups, *the critically of paying attention to every detail and of recording every detail cannot be overemphasized.* Indeed, in this area, some data or information can be lost forever—making a solution to the problem extremely difficult if not impossible. For training oneself in problem-solving, i.e., some aspects of research, the reader is urged to consult "A Problem-Solving Paradigm (PSP)" by Bagayoko, Kelley, and Hasan [3], in College Teaching. For the first time to our knowledge, there is finally a comprehensive way for teaching or learning problem-solving. The mental attributes or dispositions involved in problem-solving are often the same ones for research—even though the specific, *technical knowledge and skills* for research in different fields could be vastly different.

We assert that research proficiency through the process described above is applicable to most human activities! In particular, the actual practice of research in SMET fields and in others follows our seven (7) steps rigorously. Hence, research proficiency acquired in a discipline, except for some specific technical knowledge and skills, is transferable to research processes in many others. **This transferability (i.e., versatility) is a key reason that research proficiency is our fourth "imperative" for a successful career in SMET and other fields. When a division in a major corporation is closed, for any reasons, professionals with research proficiency will generally be transferred to other divisions or will easily find other research-based jobs in the private or public sectors. There lies the reason that research proficiency is life-long employment warranty.** In the event the reader does not know, we should underscore the loss of employment by individuals with no research experiences or skills, upon the closure of their divisions, and the great difficulties they have in finding comparable positions that pay adequately. The increasingly rapid developments in science, mathematics, engineering, and technology are fueling the changes in the job markets. *[Unfortunately, some are not still getting it that good salaries without research skills are very often traps; if and when robots, new technologies, or new knowledge render their positions irrelevant, they will find themselves in debt (house, car, and other notes) and without a meaningful prospect for employment or self-employment.]*

The above point is very difficult to understand. The difficulties stem in part from the fact that some parents or acquaintances without research experiences seem to have done or to be doing rather well! *A reason* for that situation is that when they entered the workforce, the rate of changes was very slow compared to the picture today: there were not cellular phones, Internet, genome maps, sophisticated transportation means, nano-materials, global warming, or space tourism, etc. It is therefore critical *"not to move forward to the past." A second reason* that can lead to grave errors is explained by statistics. The "impressions about some doing very well without research expertise" are very often ill informed. *Yes, exceptions are not rules. Let the rules guide you.* Indeed, with some basic knowledge of statistics, one can see that anecdotal cases, however glittering or numerous they may be, are never to be taken as central tendencies (a statistical concept) without a full knowledge of the total picture of the groups or systems under study. In other words, the relative success of a few high school or college dropouts, for the cautious thinkers, must not overshadow the dead-ends faced by the great majority of them! *Always remember and be guided by these two reasons.*

Another illustration of the *exception and rule* scenario for you and your peers or relatives follows. Knowing a few NBA or NFL draftees, who did very well, financially and otherwise, is one thing; choosing basketball or football as your profession is another. While the expanding nature of the job market in SMET and related fields can accommodate SMET graduates, particularly the ones with research skills, the NFL or NBA teams, in fixed numbers, cannot employ all college graduates who are good basket ball or football players! To understand this further, just calculate the total numbers of players on the NBA and NFL teams and compare them to the total numbers of college seniors on college teams! Do not stop there, remember also that most teams already have a full roster and only take a few draftees in a given year!

A Paper Published in the Proceedings of the 2001 Student High Technology Expo of the National Association for Equal Opportunity (NAFEO) in Higher Education, Pages 27-32. ISBN Number 0-9704609-3-7. Publisher: The Louis Stokes Louisiana Alliance for Minority Participation (http://www.ls-lamp.org), Baton Rouge, LA, 2001.

THE LAW OF PERFORMANCE: Adequate practice begets excellence in school, college and in research—the same way it does in sport!

The Power Law of Human Performance or of Practice (PLP) states that the time (T) it takes an individual to perform a given task decreases as the number of times (N) the individual practiced the task increases. In mathematical terminology, the law is [4]:

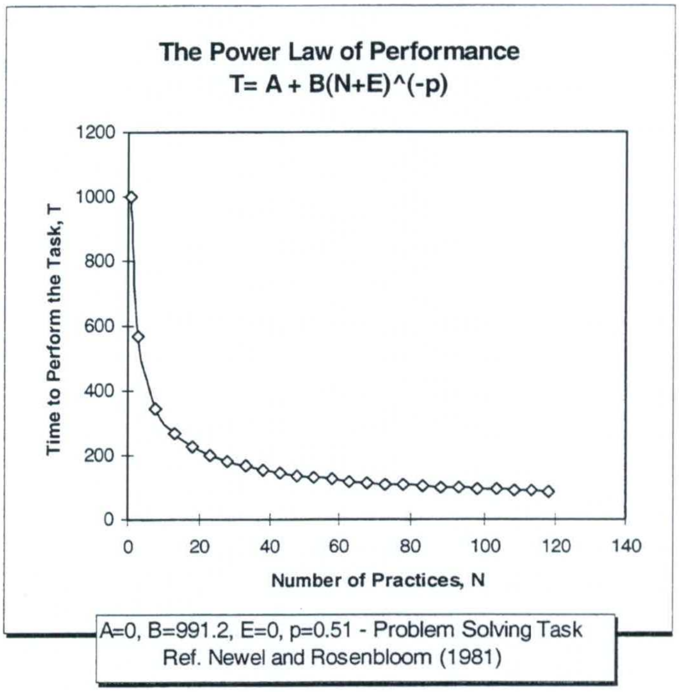
$$T = A + B\,(N + E)^{-p} \quad \text{or} \quad T = A + B/(N + E)^{p}$$

where A, B, E and p are constants that vary **(a)** with the task at hand and **(b)** with the individual performing the task. A represents a physiological limit. B and E partly denote prior experiences before the beginning of the practice sessions, and p is the learning rate. In other words, the law states that *"practice renders perfect."* This law applies to the performance of *sensory-motor (or athletic), creative (or artistic), and cognitive (or intellectual) tasks.* The shorter the time T to perform the task - *completely and correctly* - the higher the level of proficiency. *Hence, as the number of practices increases, so does the proficiency of the individual.* The figure below graphically shows the plot of the above expression for a problem solving task.

The dramatic impact of this law becomes apparent when one considers its application to several tasks over several days, months, and years. Then, it becomes clear that *genius is mostly the result of sustained, competitive practice.* The same way adequate practice, at an adequate scope and depth, is needed for the making of Olympic, National Basketball Association, National Football Association, and Major League Soccer champions and for the making of musicians and artists, the same way it is needed for the making of science, engineering, and mathematics scholars and researchers in any discipline.

Further, this law is implacable. It applies whether one likes it or not! It applies to the refinement or the enhancement of the *teaching*, mentoring, research, and writing skills of a teacher or faculty member! The law implicitly addresses the need to strive for quality! Indeed, practicing bad grammar, incorrect mathematics, etc. renders one very good at them! So, even though the power law and the law of performance do not explicitly factor in the issue of quality, they do so indirectly.

The compound law of human performance, or simply the *law of performance* (Education, Vol. 115, No. 1, pp. 31-39, 1994), is the convolution of the power law of performance as simultaneously applied to several tasks over a long period of time. The main difference between the *power law* and the *law* is that the former follows a simple equation that involves an exponent or power (i.e., p) while the mathematical form of the latter is yet to be determined. *The quintessential point here, however, stems from the fact that according to the law of human performance, the abilities, skills, and attributes (of individuals) that are meaningfully engaged and challenged in and outside the classroom (as by lessons, assignments, research)--from pre-K through graduate school and beyond — are the ones that will develop!* The law of human performance provides the scientific basis for high expectations for all students! Professional mentoring, as defined elsewhere by Bagayoko (http://www.phys.subr.edu/timbuktu.htm), provides an almost fail-safe strategy for promoting the academic excellence of all students (female or male, minority or non-minority, young or mature). Student retention, on-time graduation, and their success in graduate school are partly by-product of the quest for proficiency and excellence-- through competitive teaching, learning, and research. *It is critical to note that the same way the LP applies to the cognitive domain, the same way it applies to non-cognitive (i.e., behavioral) variables: Character and study habits are also molded through practice!*



Newel, A. and P. S. Rosenbloom (1981)."Mechanisms of Skill Acquisition," Edited by Anderson, J. R. Hillsdale, N. J.: Erlbaum

DIRECT APPLICATIONS: the need to plan and to execute (i.e., practice)

By linking prior experiences or practice to the speed with which one learns or discover new knowledge, the law of performance states that our levels of achievements in the classroom, in athletic events, artistic endeavors, and in research are determined for the most part by us—given that **we decide every day on the time we devote to various tasks**! Further, the law of performance is a great liberator that says that there is nothing wrong in not being an expert in a subject or a task at once—no one is! Hence, consulting experts, getting the appropriate materials, doing adequate practice is all that is needed.

Each and every one of the *imperative proficiencies* described above (*i.e., in language and communication, mathematics, probability and statistics, and research)* is acquired through practice! And no one should forget, in light of the meaning of B and E, that difficulties in mathematics, science, engineering, and technology courses are very often caused by an inadequacy of background, practice, prior experiences, or of studying. In fact, for individuals not suffering from a severe physiological or mental impairment, that is the case.

In particular, research expertise often requires many years of practice. Hence, the sooner one starts performing research, the better it will be. *If you missed the opportunity in high school, make certain that you start as soon as possible in college.* (And if your institution or department does not understand this point, then find one that does and that has good faculty research-mentors.) Of course, the law of performance says to remember, at the beginning of new learning experiences, that the feeling or impression of being lost is a sign that one started learning new things! (Oh, yes, I know, many students erroneously take it to mean that they are not "smart" enough. Please explain the facts to them.) At conferences, the best experts do not know or understand everything—including the ones making the presentations! So, you are not alone. And, these experts know that research questions can be found, in a quasi–infinite number, in the professional and technical literature (magazine, journals, books, etc., on paper or in electronic media) and not by looking at the sky or ground. *The experts keep on learning; according to the law of practice, that is how they built and continue to enhance their expertise!*

We explained above the need to consult several faculty members, peers, experts, etc. in order to determine the background that is needed for career options one is contemplating. The same is true for courses one has to take in college or in graduate school. Hence, there is a critical need to plan professionally, in writing. Only through such a planning can one determine indispensable background or experiences and take the needed steps to acquire them — through regular and persistent efforts. *"A college portfolio"* should be prepared by 10^{th} or 11^{th} grade students; *"a graduate school portfolio"* should be prepared by college sophomores or juniors; and *"a research career portfolio"* should be prepared by every graduate student. The preparation of these portfolios, first and foremost, brings to light needed credentials, background, experiences, etc. when there is still time to acquire them. See Reference [1] for an example of a "college portfolio" that can be easily adapted to design other portfolios noted above.

CONCLUSION

At the beginning of this presentation, I noted that it had already been delivered by Dr. Norman Y. Mineta, the Honorable US Transportation Secretary. It has also been reiterated by Dr. Henry Ponder, the President of NAFEO. Indeed, these officials just addressed you and underscored the fact that the opportunities in science, mathematics, engineering, and technology are almost limitless. Paraphrasing Dr. Mineta's statement, we see that the sky is the limit in transportation alone. (And, if you ask NASA, even the sky or ocean floor may not be limits!) We added that many interdisciplinary areas offer more opportunities than can hold on a single list. Some of these areas include Earth Science, Energy and Environmental Science, Global Climate Change Research (with possible application to other planets), Materials Science, Engineering, and Technology (MSET), Genomics and the nascent Proteomics, Agriculture Science and Technology, Biomedical Research, and many others. Honorable Dr. Mineta and Dr. Ponder acknowledged your present accomplishments, including the research you already performed and the technical presentations many of you will make in the following session.

In light of the foregoing, it is my deepest hope that you will fully utilize the content of this provocative address not only to take your accomplishments and preparedness to new heights, but also to inform many other people, including your peers, young relatives, and your descendants. *"Luck is what happens when PREPARATION (through effort or practice as per the LP)) meets or makes, recognizes, and acts on opportunity."* We are counting on you.

ANNOTATED BIBLIOGRAPHY

[1] http://www.phys.subr.edu/timbuktu/careers.htm This site provides a listed of hot links to extensive information on careers in science, mathematics, engineering, and technology. Sources include the American Institute of Physics, the American Physical Society, the American Chemical Society, the American Mathematical Society, the American Psychological Association, etc. Available information includes: how to prepare for a career, interview tips, resume preparation, free posting of a resume, etc. (Also visit the site of the American Association for the Advancement of Science: http://www.aaas.org/)

[2] Science, Vol. 292, No. 5524, Page 1971, June 15, 2001. See *"Scoop on Stats"* in the Section on Netwatch. The web site on a recently developed online statistics textbook, by David Lane at Rice University, is provided (http://www.ruf.rice.edu/~lane/rvls.html).

[3] *"A Problem-Solving Paradigm,"* D. Bagayoko, Ella L. Kelley, and Saleem Hasan. College Teaching, Vol. 48, No. 1, pp. 24-27, 2000. Understanding, knowing, and paying attention to the five (5) categories involved in problem-solving is a prerequisite for properly teaching or learning it, by design. These categories are *knowledge, skills, resource, strategy/experience, and behavioral bases* of problem solving proficiency or expertise.

[4] *"The Dynamics of Student Retention: A Review and a Prescription,"* D. Bagayoko and Ella L. Kelley. Education, Vol. 115, No. 1, Pages 31-39, 1994. This paper elaborates extensively on the Power Law of Performance and it introduces the compound law (or simply the Law) of Performance. The article utilizes the law of performance to explain the creation of educational, research, and professional value-added (high academic achievements and expertise).

[5] Jaime Escalante, in our view, rigorously applied the law of performance when he worked with his Hispanic American students to make calculus geniuses out of them. Please think about his equation that says the following: **"determination + discipline + hard work = success."** Anyone who understands and heeds this equation will be following the law of practice by devoting significantly large amounts of time to learning and research tasks at hand, and that over months and years.

[6] "*Writing for Success: A User-Friendly Manual for Effective Communication,"* By Professor Ora Plummer and Dr. Diola Bagayoko. Publisher: McGraw Hill. ISBN: 0-07-154196-9 (1998). A copy of this book was provided to student participants of this 2001 NAFEO High Tech Expo with the hope that it will be *persistently* used for "continuous improvements" of language and communication skills. Please refer to the first "imperative" discussed above. [Note: Dr. Bagayoko does not make any money from sales of this book; he donated his share of the royalties to the Southern University Foundation for the purpose of establishing and endowment for the Timbuktu Academy.]

Problem-Solving Paradigm

Diola Bagayoko, Ella L. Kelley, and Saleem Hasan

The complexity of problem solving partly explains professors' continuing efforts to develop students' problem-solving expertise (Woods 1994, 1993a, 1993b, 1987). (We use the unusual order of citation because the sequence of the author's arguments is best understood in reverse chronological order.)[1] Advances in understanding the creation of educational value added offer a comprehensive explanation of the development of problem-solving proficiency (Moore and Bagayoko 1994, Bagayoko and Kelley 1994a). Our aim is to present the resulting problem-solving paradigm (PSP), also known as the problem-solving pentagon (see figure 1).

A Problem-Solving Paradigm (PSP)

A comprehensive discussion of problem-solving scenarios might require a book. For simplicity, we will focus on academic problem solving, even though the pentagon described below is valid for real-life problems as well. One essential difference between the two, despite their overlap, is that the academic problems are generally well defined. In solving actual problems, problem definition, delineation, and redefinition pervade the entire process.

To develop the problem-solving expertise of students, we recommend that teachers make concentrated and sustained efforts to develop the following five categories. (The order of the categories is not one of decreasing or increasing importance.)

1. *Knowledge base.* Cognitively condensed and meaningfully organized knowledge is very different from a set of disjointed pieces of information. We will discuss an often neglected part of the knowledge base—the applicable language or information transmission modes (Adamczyk and Wilson 1996).

One cannot consistently and correctly apply that which one does not know critically. Cognitively condensed knowledge is organized or structured in a meaningful fashion, using causal, functional, and logical relationships (Bagayoko and Kelley 1994b). This organizing, bunching, and clustering of knowledge is a central tool for the implementation of "less is more" (AAAS 1989; NSTA 1990) through teaching and learning processes.

In chemistry and physics classes, for example, the last, cognitively condensed form of the ideal gas law that a teacher should leave with students is $PV = nRT$. Respectively, P, V, n, R, and T are the pressure, the volume, the number of moles, the ideal gas constant, and the temperature. It is only our suggestion to use this form in introducing the concept of ideal gas. The essential point is that, with $PV = nRT$, students should be able to recover any of three laws that apply when P and n, V and n, or T and n are respectively held constant. In addition, concept mapping (AAAS 1989) is one of the best ways of condensing and integrating new knowledge into an existing knowledge base.

2. *Skill base.* Cognitively condensed procedural knowledge has some overlap with the organized knowledge of category 1, even though it is distinct. This distinction is apparent in problem-solving situations that require physical dexterity. The idea that the time rate of change of distance is speed may belong to Category 1, but carrying out the differentiations, given several mathematical expressions for the distance, requires the know-how or skills in Category 2.

Procedural knowledge can be cognitively condensed or structured as discussed above. Algebra provides one of the best means of illustrating this category. Indeed, knowing how to solve a given equation is one thing, and solving it correctly is another. For the latter, one has to properly execute basic operations and the rules of exponentiation. Teaching through classroom examples and graded assignments promotes the mastery of these skills through practice.

3. *Resource base.* The nature of this base may vary drastically depending on the problem. Both human and material

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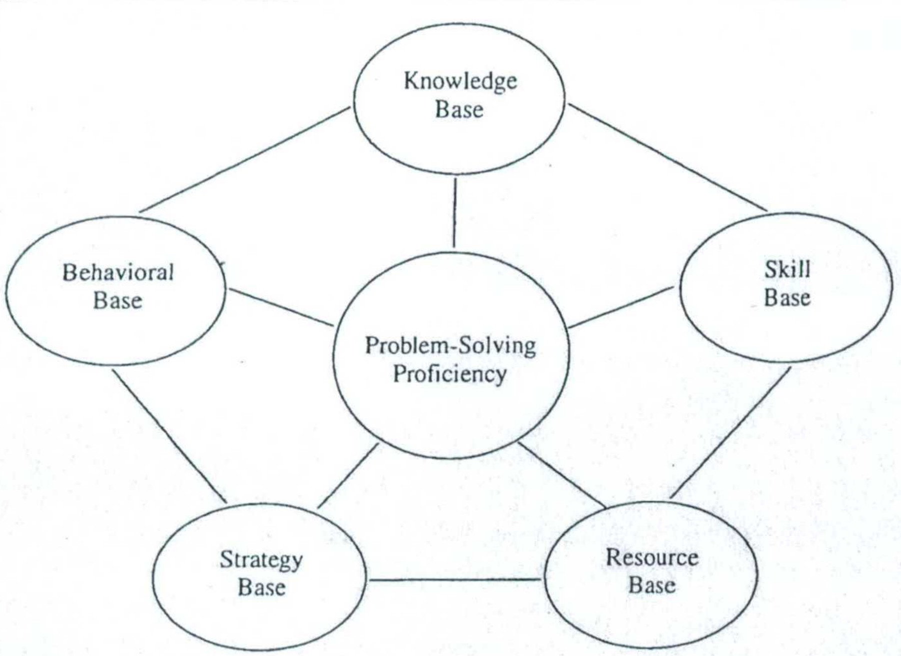

Figure 1. A Problem-Solving Paradigm (PSP)

resources are necessary. For ordinary academic problem solving, calculator, protractors, computers and applicable software products, reference books, and journals are typical material resources. In addition, for creative thinking the resource base should not be limited because new ideas may require new tools.

4. *Strategy-Experience base.* Strategy and experience may be specific to certain kinds of problems, or they may be transferable. We know that practice enhances proficiency, as dictated by the power law of performance (Bagayoko and Kelley 1994a). Strategy or method, in this category, should not be confused with the skill base in Category 2. A useful analogy is that Category 2 represents individual musicians, skilled at playing various instruments, and Category 4 refers to the conductor of the orchestra. (Room is provided for improvisation by the conductor, as problem-solving strategies do not always follow, at all stages, an algorithmic approach.)

One's strategy-experience base, Category 4, essentially grows over time. Its growth is generally concomitant with those of Categories 1, 2, and 5. Category 4 could also be called "effort," to place emphasis on the role of practice in the development of problem-solving proficiency. Teaching, then, should include judiciously selected graded assignments that will expose students to key strategies for solving problems on the topics at hand.

5. *Behavioral base.* The affective domain has a bearing on the outcome of problem-solving attempts. In particular, this category is distinguished from Category 4 in that the knowledge of, or experience with, a strategy or method is not sufficient for guaranteeing the self-discipline that is sometimes needed to adhere to it. Individual reactions to various constraints in problem solving (e.g., panic attack as opposed to strong focus), although partly determined by the other categories, strongly hinge on one's emotional and behavioral traits, partly molded through practice.

As in the other categories, students can change their behavior through training and/or practice. Failure to know adequately some basic subject content (Category 1) or to develop some key skills (Category 2) often prompts students to panic. Most professors can recount several such cases, when students *guess and hope* instead of *think and reason*. That can have a profound negative impact, including destroying self-confidence (Bagayoko and Kelley 1994a).

Unfortunately, the compound power law of performance dictates that students who frequently repeat such behavior patterns virtually make lack of confidence their second nature! Conversely, adequate preparation (Categories 1-4) reinforces self-confidence and behavioral patterns that are favorable for expert problem solving.

Application and Implications

A first implication of the above paradigm stems from its conflict with current descriptions of problem solving. Indeed, expressions such as *problem-solving skills* or *problem-solving abilities* may be construed to mean that the skills, in the sense of procedural knowledge or some innate ability, are the answers to problem solving. The problem-solving pentagon leads to the conclusion that the word *skills,* in its common sense, represents at best one-fifth of what is required for problem-solving expertise. We therefore suggest that *problem-solving pentagon* or *problem-solving expertise* replace the potentially misleading term *problem-solving skills.*

The problem-solving pentagon (PSP) shows that the failure of some old approaches to teaching problem solving stems not so much from flaws in the approaches as from a neglect of the other sides of the pentagon. One of these methods consists of having the instructor solve sample problems while the students watch. That approach is very valuable, if properly implemented. We will discuss an effective use of this approach, along with others.

Every fall and spring semester, the physics department enrolls 140-170 students in other sciences and engineering in General Physics, a calculus-based, introductory mechanics course. These students attend two-hour sessions of problem solving every week, in addition to the lecture and laboratory sessions. There generally are six to eight sections of problem solving. Over the four years 1986–1990, students in the two sections where the problem-solving paradigm was rigorously applied have clearly outperformed the others in two ways. Their averages on the common lecture class exams have consistently been above those of the students in the other problem-solving classes, and 91 percent of the time, one of the students in the PSP group has made the highest score on the common exams. We attribute the differences to the implementation of the problem-solving paradigm.

"Slow" and Guided Solving

In particular, one experience that the students in other sections did not have was the "slow and PSP-guided example problem-solving." In the selected sections, very few problems, different in nature and complexity, were solved in class. In general, only one example problem was collectively solved per week. In keeping with the paradigm, the problem was solved interactively using Socratic dialogue. The students did the thinking while the teacher mostly guided, wrote on the board, and commented extensively. The problems involved a combination of fundamental principles or definitions, key laws, and several skills to obtain peripheral facts from the core or central theme around which the rest is condensed.

The key to the success of this approach, we think, resides in

1. the Socratic dialogues that engage the students,
2. extensive comments at every step, to note the category or categories of the pentagon that made the successful step possible, and
3. the relatively slow pace (due in part to the dialogues) that helps students remember not only the concepts and skills but also some strategies and related behavioral patterns.

It is important that the instructor help the students to understand the relevance of every category of the pentagon. The need to read carefully and to study a problem (Categories 5 and 4) and the indispensable role of adequate knowledge (Category 1) and skills (Category 2) must become obvious to the students.

To further reinforce adherence to the paradigm, we gave weekly quizzes of ten to fifteen minutes. The quizzes did not stress the speedy recall of a plethora of minutiae, but rather they reinforced the mastery of cores of cognitively condensed knowledge and skills. We assigned weekly homework problem sets, collected them the following week, and graded and returned them the next. As per the power law of performance, there *is no substitute for actual practice*. The students in the selected sections wasted much less time attempting to guess or to apply a key principle, law, or skill that they did not know.

Exposure to and practice of the needed knowledge, skills, strategies, and behavioral traits lead, over time, to building the students' problem-solving proficiency.

Discussion

Contrary to the belief of some practitioners that doing several homework problems does not develop problem-solving skill, we assert that practice does enhance problem-solving proficiency by virtue of the compound law of performance. The mathematical formulation of the power law of performance has been discussed by Bagayoko and Kelley (1994a). Qualitatively, the law states that the time it takes a person to perform a sensory-motor or a cognitive task decreases as the number of times that the person practices the task or related ones increases. The composition of the power law—for which no single mathematical formulation is yet available—follows from compounding the results from the power law for a series of tasks over relatively long periods.

It is critical to note that the development of problem-solving proficiency is clearly explained, for the most part, by the compound or integrated law of human performance. Namely, adequate exposure to and practice of the applicable knowledge, skill, strategies, and behavioral traits leads, over time, to building the students' problem-solving proficiency. Thus, the problem solver grasps the importance of harnessing the needed resources for the problems at hand. To this end, we underscore the pivotal role of teaching and the related feedback in developing the problem-solving proficiency of students. Good teaching develops students' proficiency through (*a*) modeling of the use of the categories identified above, (*b*) graded assignments, and (*c*) testing. The testing must emphasize and require thinking as opposed to the recall of disjointed facts.

Students' evaluation of the problem-solving courses that employed this paradigm averaged a rating between 4 and 5, out of 5, each semester, on a twelve-item instrument. Perhaps the most rewarding aspect of our experience has been several anecdotal accounts from our students that they have learned to think and that they employed their training in the course to problem solving in other courses (mostly chemistry and engineering).

That good evaluation notwithstanding, at the beginning of the course, students always showed some resistance to this approach. In particular, they had to be "forced" to follow our unfailing demand that they thoroughly read and study a problem (Category 5) before attempting to solve it and that they demonstrate mastery of a certain few fundamental concepts and laws (Category 1) before trying to apply them.

From our experience, this paradigm permits a clear dissection of students' problem-solving difficulties. Early in the courses, we identified student deficiencies in mathematics knowledge (Category 1) and skill (Category 2), as in algebraic and calculus operations. The deficiencies were remedied by having students read pertinent book chapters and handouts and then giving them physics homework assignments, quizzes, and tests on the contents of assignments.

We found that the paradigm works very well only when it is fully implemented, that is, when every category receives explicit attention. This conclusion is strongly suggested by the National Science Education Standards (NRC, 1996) and in teaching videos produced by the Third International Mathematics and Science Study in 1996.[2] When every category is included, practice over time indeed enhances problem-solving proficiency.

ACKNOWLEDGMENTS

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NOTES

1. See the following articles by D. R. Woods: "New Approaches for Developing PS Skills: What's New in Problem-Solving?" *Journal of College Science Teaching* 23(3) (1994): 157–8. "Problem-Solving—What Doesn't Seem to Work, *Journal of College Science Teaching* 22(1) (1993a): 57–8; "PS—Where Are We Now?" *Journal of College Science Teaching* 22(5)(1993b): 312–14; and "How Might I Teach Problem-Solving?" in *Developing Critical Thinking and Problem-Solving Abilities*, ed. J. E. Stice. (San Francisco: Jossey-Bass, 1987).

2. VHS (or CD-ROM) video examples from the Eighth-Grade Mathematics Lessons: U.S., Japan, and Germany. Available from: Superintendent of Documents, P.O. Box 37954, Pittsburgh, Pennsylvania 15250-7954, USA. The reference number for the VHS Video Examples is GPO #065-00-01025-9.

REFERENCES

American Association for the Advancement of Science (AAAS). 1989. *Science for all Americans: Project 2061.* Washington, D.C.: AAAS.

Adamczyk, P., and M. Wilson. 1996. Using concept maps with trainee physics teachers. *Physics Education* 31(6): 374–81.

Bagayoko, D., and E. L. Kelley. 1994a. The dynamics of student retention: A review and a prescription. *Education* 115(1): 319.

———. 1994b. Cognitive condensation for mastery teaching and learning. *Education* 115(1): 19–25.

Moore, W. E., and D. Bagayoko. 1994. A paradigm of education: Basic principles, the model of the Timbuktu Academy. *Education* 115(1): 11–8.

National Research Council. 1996. *National science education standards.* Washington, D.C.: National Academy Press.

National Science Teachers Association. 1990. *Scope, sequence, and coordination (SSC).* Washington, D.C.: National Science Teachers Association.

Paul, R., 1990. *Critical thinking: What every person needs to survive in a rapidly changing world.* Rohnert Park, Calif.: Sonoma State University, Center for Critical Thinking and Morale Critique.

Woods, D. R. See note 1 above.

Fundamentals of Mentoring and Networking

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Abstract

The aim of this article is to provide an overview of mentoring, in its complexity, and to underscore its importance in the creation of educational, research, and professional value-added. Networking, a prevailing form of peer-mentoring, is directly relevant to attaining, maintaining, and enhancing professional proficiency and competitiveness by junior and senior faculty members as well as other professionals in public and private sectors. The distinction claimed by this work stems from the empirically-established and practice-verified nature of its basic precepts as they relate to mentoring that is viewed as an emerging, interdisciplinary field of scholarly inquiry. The power law of human performance and its extension, the integrated law of performance (ILP), provide a foundation for our approach. It is hoped that the reader will see herein a clear, fail-safe, and comprehensive road-map for the pursuit of competitiveness by students and by faculty members.

Mentoring

Mentoring is the general, pervasive, and ubiquitous process by which value systems, cultures, knowledge, and skills are transmitted from one generation to the next and within a generation (Bagayoko, 1997). The goal of proper mentoring is to prepare and equip the mentee to make positive contributions to society—including serving as a model for peers, immediate family, and society at large. Mentoring is perhaps best defined by examining some of its intrinsic characteristics as given below.

- A mentor/mentee or mentor/protégé relationship aims to prepare the mentee to make positive and significant contributions to society. In the case of college student mentoring, superior scholastic and research achievements and personal growth are central objectives of mentoring.

- Mentoring often entails a one-to-one professional relationship between the mentor and the mentee. The various forms of support (financial, moral, access to resources, etc.) the mentor provides for the mentee are generally aimed at: a) integrating the mentee into the applicable professional activities (e.g., studying, learning, and conducting research in a college environment); and b) integrating the mentee socially. Functional, social integration is distinguished from dysfunctional, social submersion!

- Some professional interests of the mentor partly ensure that the mentee is appropriately challenged, as required by the integrated law of human performance, discussed below, for the competitive preparation of the mentee. In the case of the mentoring of a graduate student or of a junior faculty member, it is often in the professional interest of the senior faculty mentor to have the mentee make contributions to a research project.

- The mentor actually serves to integrate the mentee into a complex network. Some details on how this integration is accomplished, for college student mentoring, are provided by Bagayoko in Reference 1 and summarized below.

A mentoring relationship is different from a regular teacher/student relation, even though the latter, through cooperative learning processes and "implicit" role modeling by the instructor, could have some mentoring features. The fact that mentoring addresses cognitive and non-cognitive (e.g., behavior, value system, and provision of specific support) variables partly distinguishes mentoring from classroom instruction that is just a part of it. Mentoring enables quality learning.

Research lends itself to mentoring in almost all situations. It serves to give an experiential application (i.e., relevancy) of classroom activities and lessons. Mentoring is a strong coupling between research and teaching and learning. It ideally integrates research and education.

Holistic Mentoring is characterized by "comprehensiveness" and thoroughness, as opposed to *ad-hoc*, anecdotal, or incidental cases and many forms of role modeling. The reader is urged to see the ten (10) mentoring activities of the undergraduate component of the Timbuktu Academy for an illustration of holistic mentoring (http://www.phys.subr.edu/timbuktu.htm). An abridged version of these activities is provided below. Reference 1 provides a detailed definition of holistic mentoring.

Systemic Mentoring is characterized by the weaving of mentoring processes, interests, and activities into the fabric of the applicable organization (e.g., college, agency, company, department, research center, or other functional units). In cases of systemic mentoring, mentoring is generally and adequately reflected:

1) in the expectations of the institution or organization (verbally and in writing);
2) in the reward or incentive structures (e.g., raises and promotions);
3) in the budget (total or leveraged support); and
4) in the evaluation instruments and processes

Without (4), (3) may be a waste of funds and (1) and (2) may not have much meaning.

An example of the institutionalized, systemic mentoring in science, engineering, and mathematics units can be seen at Southern University and A&M College in Baton Rouge. In each of these units a quarter time release from teaching is provided to a faculty member who works closely with the department chairperson and serves as the mentoring coordinator. (Naturally, mentees are assigned to most faculty members, taking into account students' classification, research, and other interests.) Many Louis Stokes-Louisiana Alliance for Minority Participation (LS-LAMP) and other Alliance for Minority Participation (AMP) institutions are making steady progress towards the application to mentoring of the same professionalism, creativity, and rigor we bring to bear in research!

Networking is a feature of mentoring that is growing in importance. Social and professional clubs, organizations, and societies (James Stith, 1999) are typical platforms where peer-mentoring takes place. With the advent and continuing sophistication of telecommunication technologies, as thoroughly described by James Gates (1999), networking is currently within the reach of most individuals. For faculty members, this networking may start with senior and peer faculty members in the department or institution. The global village, however, is within the reach of everyone—the key is to understand that the initiative, for full participation, rests in part with the prospective mentee (i.e., junior faculty)!

A Summary Road-Map for Holistic and Systemic Mentoring

We provide below some key elements of holistic and systemic mentoring (Bagayoko, 1997). They are intended to aid in a) the implementation or enhancement of student mentoring by faculty members and b) the establishment or reinforcement of systemic mentoring practices. While these elements are discussed below in connection with undergraduate student mentoring, they are directly applicable (transferable, with little change, if any) to the mentoring of graduate students, junior faculty members, research associates, or any employee. This assertion holds for public and private sectors.

Holistic Mentoring by individuals includes:

- listening to the mentees, knowing their assumptions, and avoiding some of your own.
- informing the mentees about expectations (the power law of human performance provides a scientific basis for high expectation for all students), long-term benefits of their work, proper course sequencing, and available services, including those for tutoring.
- supporting the mentees financially (from a diversified funding base, including Federal Financial Aid, assistantships, and fellowships), and other ways (e.g., resources and seminars). This support is to provide opportunities and must never give the impression of guaranteeing success without the mentees' sustained efforts to achieve. For junior faculty members, grants/contracts and related opportunities replace assistantships/scholarships.
- challenging the mentees in course work, GRE preparation, communication and computer skills enhancement, and in research and scholarly activities, including writing reports (practice), and

making presentations (practice) for junior faculty members. Staying current is the issue.

- monitoring the activities and results of the mentees. Records of the periodic reviews are to be in the portfolios of the student mentees; at an absolute minimum, there should be one review/meeting at the beginning of the semester (course sequencing and review of last semester's grades), one to discuss mid-term grades, and one around the end of the semester (to prepare in time for finals). All activities and results, including research and general enhancement activities, are to be reviewed. Without proper monitoring, one cannot write a well-informed recommendation for graduate school or other purposes; a different kind of "monitoring," e.g., awareness of tasks and of accomplishments is needed for colleague mentees—junior faculty members.

- congratulating when appropriate—this is needed for good grades, research accomplishments, or model behavior. Positive reinforcement is needed—we get it with funding, publications, pay raises, etc.; students or junior faculty/employees need this basic reinforcement (verbally and sometimes in writing).

- admonishing, stating disapproval, and reproving, when needed, but always in a positive tone.

- guiding, e.g., to graduate school; or to greater heights of reform—teaching, mentoring, research, for junior faculty and research associates or new employees (in a corporation);

- writing substantive and informed letters of recommendation. This requires maintaining a portfolio for each student mentee; some knowledge is also needed for a meaningful recommendation for a junior faculty member or a research associate.

Holistic mentoring, in a college environment, ensures the academic and social integration of the mentees (Bagayoko and Kelley, 1994). In a research center or laboratory, holistic mentoring ensures the professional, research, and social integration of the mentees. The sense of learning, of contributing, and of belonging are often a clear indication of the integration noted above. The mentoring booklet published by the National Academy of Science (1997) elaborates on most of these mentoring activities and provides illustrative case studies. It is an inexpensive and very practical guidepost.

Systemic Mentoring includes:

- the weaving of mentoring interests, processes, etc. into the fabric of the department, unit, organization, research center or laboratory and of the whole institution or organization. To do so often requires a mentoring coordinator per department or unit. It also requires, in the long term, an explicit place for mentoring in (a) the definition of the duties and responsibilities of faculty, senior personnel, or managers and (b) the incentive or reward structures.

  On a college campus, the role of a departmental mentoring coordinator includes working with the department chair to see to it that students who need tutoring receive it. Tutoring should be made available at a fixed place, at regular hours, and the tutors should include faculty (one supervisor) and well-trained advanced undergraduates and graduate students. If the actual utilization of technology is taking place, then one expects E-mail communication to be utilized in mentoring and for setting-up some advisement or tutoring meetings, appointments, and more. (For research organization, the coordinator works with the Director of the Center or Laboratory.)

- maintaining a comprehensive data base that captures pertinent information on background, grades, research accomplishments, publication and presentation record, etc. Mentors provide the data on their mentees to the coordinator. Another form of data gathering is needed for the mentoring of junior faculty members or of new employees.

- following-up with the mentees, even after graduation. This entails knowing the graduate school or the employment information of each graduate.

- writing proposals to secure funding from a variety of sources including federal, industrial, and foundation sources, and promoting the inclusion of financial support for mentees in other proposals not necessarily devoted to mentoring activities or projects.

- placing mentees in research projects—on and off campus—and in summer or academic year internship positions (availing opportunities to junior faculty members or new employees).

- interfacing professionally with (a) the Admissions and Recruitment Office, (b) the Junior Division, (c) the Honors College, for matters of recruitment and mentoring, and (d) the Office of Grants and Sponsored Programs for funding opportunities. This list is not exhaustive.

A systemic approach to mentoring has always been, and this is a well kept secret, the engine that maintains the competitive edge of units, departments, research centers, corporations, etc. that implement it! A good understanding of the concept of "distributed responsibilities" and of "shared credits" substitutes cooperative learning/working and synergy to "retrograde competition." Then, positive emulation pervades the stimulated working environment. Individuals discover their real competition: each competes with him/herself to increase his/her contributions—in quantity and quality—to the organization. Continual professional development is understood. The laws discussed below provides the profound reason that mentoring is needed by students, junior faculty, and by others (e.g., networking and peer-mentoring are needed by anyone who is to remain competitive in some endeavors).

The Integrated Law of Human Performance

The power law of human performance (Newel and Rosenbloom, 1981) and its extension, the integrated or compound law of human performance (Bagayoko and Kelley, 1994) provide a rigorous, scientific rationale or reason for holistic and systemic mentoring. It is highly empowering as it shows that efforts and practices—preferably with the assistance of experts—will lead anyone to competitiveness in any endeavor!

We have learned not to be stressed, ashamed, or apologetic for not being experts in different areas. We have learned to recall the integrated law of human performance and to begin learning earnestly whatever we have to learn. We know that, with time and adequate efforts, we shall reach any level of expertise, proficiency, or competitiveness!

The Power Law of Performance or of Practice (PLP) states that the time (T) it takes an individual to perform a given task decreases as the number of times (N) the individual practiced the task increases. In mathematical terminology, the law is (Newel and Rosenbloom, 1981):

$$T = A + B\,(N + E)^{-p} \quad \text{or} \quad T = A + B/(N + E)^{p}$$

where A, B, E and p are constants that vary (a) with the task at hand and (b) with the individual performing the task. A represents a physiological limit. B and E partly denote prior experiences before the beginning of the practice sessions, and p is the learning rate. In other words, the law states that 'practice renders perfect.' This law applies to the performance of sensory-motor (or athletic), creative (or artistic), and cognitive (or intellectual) tasks.

The following figure graphically shows the plot of the above mathematical expression of the power law of human performance for a problem-solving task. The time to perform the task is shown on the vertical axis while the number of times the individual practiced the task (N) is on the horizontal axis. The reader should note the greater rate increase in proficiency (i.e., the decrease in the time) for the first practices. Naturally, for very large numbers of practices, the increase in proficiency per unit practice gets smaller.

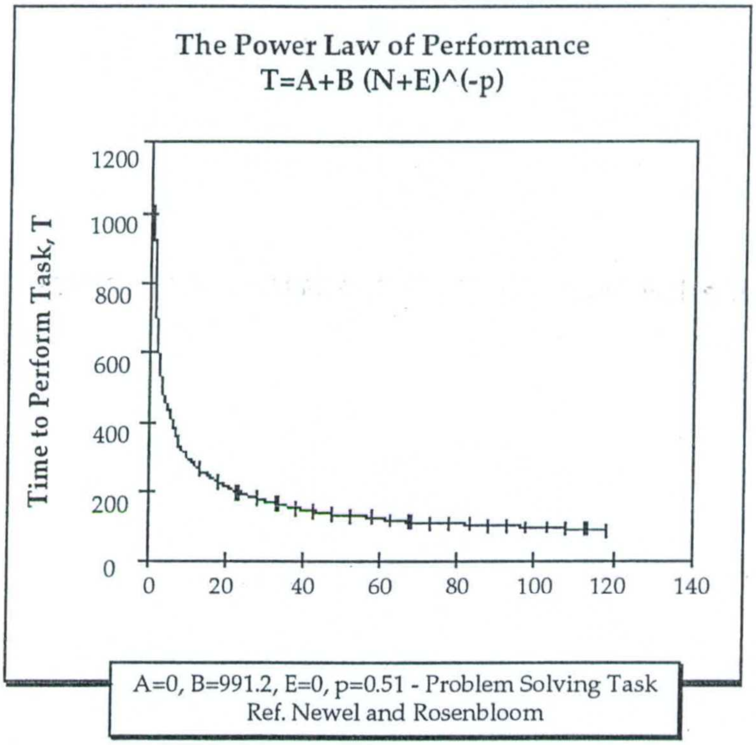

Figure 1. The Power Law of Human Performance. The shorter the time T to perform the task, *completely and correctly*, the higher the level of proficiency. *Hence, as the number of practices increases so does the proficiency of the individual.*

The dramatic impact of this law becomes apparent when one considers its application over several tasks and several days, months, and years. Then it becomes clear that genius is mostly the result of sustained practice. The same way adequate practice, at an adequate scope and depth, is needed for the making of Olympic, National Basketball Association, National Football League, and Major League Soccer champions and for the making of musicians and artists, the same way it is needed for the making of science, engineering, and mathematics scholars, including scholars in the social and behavioral sciences.

Further, this law is implacable. It applies whether one likes it or not! It applies to the refinement of the enhancement of the teaching, mentoring, research, and writing skills of a faculty member or of a mentee! These points are discussed further by Bagayoko and Kelley (1994) and Moore and Bagayoko (1994) in connection with the explanation of the creation of educational value added from K through graduate school and beyond.

The integrated or compound law of human performance (Bagayoko and Kelley, 1994), is the convolution of the power law of performance as simultaneously applied to several tasks over a long period of time. The main difference between the power law and the integrated law is that the former follows a simple equation that involves an exponent (i.e., p) while the mathematical form of the latter is yet to be determined. The quintessential point here, however, stems from the fact that according to the integrated law of human performance, the abilities, skills, and attributes of students (or mentees) that are meaningfully engaged and challenged in and outside (as by mentoring activities) the classroom from K through graduate school and beyond are the ones that will develop!

The integrated law of human performance provides the scientific basis for high expectations for all students! This point is rigorously established by Bagayoko and Kelley (1994). Professional mentoring, as defined above, provides an almost fail-safe strategy for promoting the academic excellence of all students and the professional growth of all faculty members, beginning with the junior faculty! In general, the integrated law of human performance is the tool for increasing proficiency or expertise in teaching, mentoring, learning, networking, developing proposals, conducting research, publishing, etc.

This integrated or compound law of human performance is the "Rosetta Stone" of education and of the development of professional competency or competitiveness. This assertion is obvious in sports and in artistic endeavors. As per this law, the optimum acquisition of expertise in complex processes (e.g., learning, proposal development, research, teaching, and related technology integration) requires mentoring (guidance and support), networking, and practice.

Epilogue

Complex processes generally involve several individuals playing their respective role. This situation led the Timbuktu Academy to introduce the concept of distributed responsibilities and of shared credits. This concept is rooted in that of ultimate value. Various parts of the functionally necessary core of a system could have vastly different prices even though the ultimate value of each one of them is that of the properly operating system. Cars and computers provide common examples. While the engine has a value (i.e., price) much higher than that of the tube bringing the fuel to the engine, these two items have the same ultimate value in the sense that the car will get nowhere without either one of them working properly! In a situation of distributed responsibilities and of shared credits, a problem is that individuals, groups, organizations, etc. could conveniently blame everything on others without taking stock into what exactly they have done themselves!

For mentoring and networking, the responsibilities are distributed between many individuals (faculty, students, center directors, junior scholars, scientists, engineers, etc.), institutional units (a department, a college, research centers, laboratories, institutes, etc.) and external entities (funding agencies, policy makers, etc.)! Responsibilities are distributed and credits are shared. To understand this concept in a profound fashion is to begin good practices of holistic and systemic mentoring and networking for the training of the next generation of productive citizens, managers, and research scholars, and for continual, professional development. We have learned, through practice, (a) not to be misled again by those 'majoring' in blaming others, (b) consistently, thoroughly, and persistently doing and documenting the role we are supposed to play, and (c) politely, persuasively, and persistently requesting that members of a vast network or web of peers or administrators play their roles, whenever needed! It appears that playing one's role professionally is the best way for getting others to cooperate—without saying one word. Good deeds are louder that words!

The practice of mentoring and networking creates and maintains the needed support system and environment in which individuals develop and grow—professionally and otherwise. It is the human equivalent of the proper ecosystem for a plant. This contention is corroborated by human experience through the ages and through different cultures. Indications of the veracity of this proposition include biographies, implicit learning, and the reader's own experiences. The mode of transmission of "knowledge and skills," before the advent of formal schooling, generally included mentoring (apprenticeship, hands-on, and experiential learning).

Annotated Bibliography

Bagayoko, D. "Mentoring: a Strategy for Increasing Minority Participation." *Proceedings, National Conference on the Role of Social and Behavioral Science (SBS) Careers in the 21st Century,* New Orleans, Louisiana (April, 1997). Edited by Dr. Emmanual Osagie, Professor of Economics, Associate Vice Chancellor for Research, Southern University and A&M College, Baton Rouge, Louisiana.

This paper is perhaps the one addressing most of the aspects of mentoring as noted in this presentation.

Bagayoko, D. and Ella L. Kelley. "The Dynamics of Student Retention, a Review and a Prescription." *Education* 115, no. 1 (fall, 1994): 31-39.

This publication explains the process of creating educational value added, from K through graduate school and beyond, using the power law and the compound or integrated law of human performance.

Gates, James. "Information-Age Technology: An Opportunity for Enhanced Faculty Effectiveness." *Scholarly Guideposts for Junior Faculty*

Washington, D.C.: Quality Education for Minorities (QEM) Network (1999.

Moore, William and Diola Bagayoko. "A Paradigm of Education: The Model of the Timbuktu Academy." *Education* 115, no. 1 (1994): 11-18.

This paper explains the cumulative build-up of academic preparedness of students from K through 12th grade and beyond. It concomitantly delves into the deleterious effect of inadequate teaching and learning and the resulting deficit of academic achievements or preparedness. The article provides an overview of the systemic mentoring activities of the Timbuktu Academy at the undergraduate level.

National Academy of Sciences, National Academy of Engineering, and Institute of Medicine. *Advisor, Teacher, Role Model, Friend: On Being a Mentor to Students in Science and Engineering*. Washington, D.C.: National Academy Press (1997).

Newel, A. and P. S. Rosenbloom. *Mechanisms of Skill Acquisition.* Edited by J. R. Anderson. Hillsdale, N.J.: Erlbaum (1981).

Stith, James. "Getting Actively Involved in Professional Organizations." *Scholarly Guideposts for Junior Faculty*. Washington, D.C.: Quality Education for Minorities (QEM) Network (1999).

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Predictions of electronic, structural, and elastic properties of cubic InN

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Predictions of electronic, structural, and elastic properties of cubic InN

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We present theoretical predictions of electronic, structural, and elastic properties of cubic indium nitride in the zine-blende structure (*c*-InN). Our *ab initio*, self-consistent calculations employed a local density approximation potential and the Bagayoko, Zhao, and Williams implementation of the linear combination of atomic orbitals. The theoretical equilibrium lattice constant is 5.017 Å, the band gap is 0.65 eV, and the bulk modulus is 145 GPa. The band gap is 0.74 eV at an experimental lattice constant of 4.98 Å. © *2004 American Institute of Physics*. [DOI: 10.1063/1.1790064]

I. INTRODUCTION AND MOTIVATIONS

Several review papers[1–4] have discussed the properties and applications of wurtzite and zinc-blende indium nitride (*c*-InN). In particular, the value of the band gap of wurtzite InN (*w*-InN) has recently attracted much interest[3–5] due to seemingly conflicting findings from experimental investigations. The current and potential applications of InN based semiconductor devices certainly warrant a rapid resolution of the unsettled issues relative to these important materials.[1–5] Indeed, light emitting diodes (LEDs), laser diodes (LDs), and photodiodes (PDs), over a wide range of energy, from ultraviolet to infrared wavelengths, are some of these applications of InN based semiconductors. The direct band gaps of high quality wurtzite InN films are reported[3–5] to be from 0.65 to 1 eV, depending on carrier concentration and other sample characteristics. The band gap of cubic InN (*c*-InN) is expected to be in this range or slightly below it. Hence, InN films could be critical for the fabrication of high speed LDs and PDs for optical communication systems.[3] Unlike *w*-InN, the most stable phase of InN in ordinary conditions, much remains to the known about *c*-InN. This situation is partly due to the serious difficulties associated with the growth of *c*-InN.[3,4]

These difficulties are apparent in the work of Yamamoto *et al.*[6] who grew *c*-InN on GaAs and α-Al_2O_3 substrates. They reported the appearance of *w*-InN when the film thickness was over 0.05 μm, and at thicknesses over 0.2 μm, the *c*-InN films grown on GaAs were completely covered by hexagonal indium nitride. The films grown on sapphire contained columnar, fibrous structures. Unlike Yamamoto *et al.*[6] who utilized metalorganic vapor-phase epitaxy (MOVPE) Tabata *et al.*,[7] Chandrasekhar *et al.*,[8] and Cimalla *et al.*[9] employed molecular beam epitaxy (MBE) to grow *c*-InN films. These authors reported values of the lattice constant of *c*-InN of 4.97±0.01, 4.980, and 4.986 Å, respectively. We are unaware of reports of experimental investigations of the electronic and elastic properties of *c*-InN. Hence, an aim of this work is to predict electronic and related properties of *c*-InN, including the band gap.

The need for this work is partly underscored by the disagreement between previous theoretical findings.[10–22] Previous local density approximation (LDA) calculations that employed the pseudopotential (PP) method produced negative band gaps ranging[10,11,13–15,19] from −0.18 to −0.40 eV. Other LDA calculations,[11,12,16,19] using variations of the linearized augmented plane wave (LAPW),[11,12] linear muffin-tin orbital (LMTO),[16] and the atomic sphere approximation (ASA) (Ref. 19) obtained *c*-InN band gaps of 0.08–0.48 eV. The generalized gradient approximation (GGA),[11,13] within the pseudopotential approach, led to a gap value[13] of −0.55 eV. Self-interaction corrections to LDA, quasiparticle (QP) approaches, and exact exchange calculations reported *c*-InN band gaps of 0.43−1.40 eV as shown in Table I below. The very recent empirical pseudopotential result of Fritsch *et al.*[22] is 0.592 eV for the band gap of *c*-InN. Our focus here is mainly on the LDA results that are very small or negative for the band gap of *c*-InN. This situation constitutes another motivation for this work, besides the lack of experimental data on the electronic and related properties of *c*-InN. Our LDA calculations recently resolved the controversy that was surrounding the band gap of wurtzite InN.[23] In particular, our LDA calculations, within the Bagayoko, Zhao, and Williams (BZW) implementation of the linear combination of atomic orbitals (LCAO) method, obtained a *w*-InN band gap of 0.88 eV, in very good agreement with measurements from a recent series of experimental investigations.[23]

Further, utilizing features of the calculated density of states (DOS), we showed[23] the possibility of obtaining a gap as large as 2 eV if optical absorption is the only measurement technique utilized. Difficulties in precisely determining the band edge, analysis techniques, and related uncertainties explain this assertion. Our work on *w*-InN added to a series of articles according to which it is no longer correct to state that local density approximation woefully underestimates the band gaps of semiconductors. Hence, and in the light of the mostly negative values of the band gap of *c*-InN, there exists a compelling rationale for an implementation of the LDA that does not suffer from an effect[24–26] believed to be mostly responsible of the dismal underestimation of band gaps. Incidentally, the band gap problem was actually a symptom of a more general and unrecognized problem stemming from unoccupied levels or bands that are affected by the effect referenced above and recalled below.

TABLE I. Experimental and theoretical lattice constants (a, in angstroms) for *c*-InN, along with the calculated values of the bulk modulus gigapascal and of the fundamental band gap (eV). Results in the last three columns, for a given row, are from the reference cited in that row.

	Computational Method	*a*(Å)	*B*(GPa)	*Eg*(eV)
	LCAO-BZW (Present work)	5.017	145	+0.65
		4.98		+0.74
		4.95	145	−0.36[a]
		5.004	140	−0.40[b]
	Pseudopotential Method (PP)	4.95	145[c]	
		4.97[d]		
		4.932	140	−0.35[e]
		4.788	155[f]	
Local Density Approximation (LDA) Potentials				−0.18[g]
	LAPW	4.94	145[c]	
	Full potential LAPW			−0.11[h]
		5.03	138	−0.48[h]
	Full Potential LMTO			−0.4[i]
		4.92	139[j]	
	Atomic sphere approximation (ASA)			−0.1[i]
				+0.02 and +0.08[k]
Generalized gradient approximation (GGA)	PP	5.06	120[c]	
		5.109	118	−0.55[b]
LDA plus self-interaction correction (SIC)				+0.43[a]
		5.05[d]		
QP Calculation	PP			+0.52[a]
QP+SIC	PP			+1.31[a]
DFT Exact Exchange				+1.4[g]
DFT, SX	ASA			+1.3[i]
Estimate of the bulk modulus of zinc-blende indium nitride (*c*-InN) using elastic properties of wurtzite InN			137[l]	
Empirical Pseudopotential Calculations (EMP)				+0.592[m]
Experimental: Measured lattice constants		4.97±0.01[n]		
		4.98[o]		
		4.986[p]		

[a]Reference 10.
[b]Reference 13.
[c]Reference 11.
[d]Reference 15.
[e]Reference 18.
[f]Reference 21.
[g]Reference 14.
[h]Reference 12.
[i]Reference 16.
[j]Reference 17.
[k]Reference 19.
[l]Reference 20.
[m]Reference 22.
[n]Reference 7.
[o]Reference 8.
[p]Reference 9.

II. METHOD AND COMPUTATIONAL DETAILS

We performed zero temperature, nonrelativistic calculations of the electronic and related properties of *c*-InN. Our *ab inito*, self-consistent calculations employed the local density approximation potential of Ceperley and Alder[27] as parametrized by Perdew and Zunger.[28] As stated above, we used the LCAO. The feature distinguishing our computational method from the previous investigations noted above consists of our implementation of the BZW procedure. In so doing, we started the calculations for *c*-InN with a minimal basis set. We subsequently performed several other self-consistent calculations with larger and larger basis sets. The basis set for any of these calculations was obtained by augmenting the one for the previous calculation with the orbital describing the next excited level of the atomic or ionic species present in the system. The occupied bands of a given calculation are compared to those of the previous. These comparisons, particularly for the first two calculations, often show differences (in numerical values, branching, or curvature). This process continues until the occupied energies from a calculation are equal, within computational uncertainties, to their corresponding ones from the calculation that follows it. Then, the output of the former calculation provides the physical description of the material under study and the related basis set is dubbed the optimal basis set. According to the Rayleigh theorem,[26] some of the *unoccupied bands* from the latter may be lower than their counterpart from the former.[24–26,29,30]

The above additional lowering is the *basis set* and *variational* effect inherently associated with variational calculations of the Rayleigh-Ritz type. In the iterative process, the use of the wave functions for the occupied states *only* in the construction of the charge density, and hence the potential and the Hamiltonian, ensures the exhaustion of the accounting for the physical interactions when the occupied energies converge vis-a-vis the size of the basis set. As fully explained elsewhere,[24–26,29] however, some unoccupied energies will continue to be lowered as the basis set is increased beyond the optimal one. The sizes of the minimal and optimal basis sets vary vastly with the type of functions in the

TABLE II. Eigenvalues (eV), along high symmetry points, for zinc-blende indium nitride (*c*-InN) as obtained from LDA-BZW calculations for $a = 5.017$ Å, the theoretical equilibrium value. The Fermi energy of −0.216 87 eV is set to zero in the table.

L	Γ	X	K
−15.5192	−14.8427	−15.6493	−15.5949
−14.7559	−14.8427	−14.7301	−14.7034
−14.7559	−14.8427	−14.5254	−14.5837
−14.4740	−14.5336	−14.5254	−14.5739
−14.4740	−14.5336	−14.4463	−14.4865
−11.7624	−14.1793	−11.3085	−11.2078
−5.5713	0.0000	−4.7495	−4.5900
−0.8335	0.0000	−2.2093	−3.3631
−0.8335	0.0000	−2.2093	−1.7848
4.0316	0.6536	4.1816	5.6110
8.4339	9.7615	6.8978	7.1493
10.6892	9.7615	11.8922	10.5553
10.6892	9.7615	11.8922	11.6130

atomic orbitals (i.e., exponential, Gaussian, plane wave functions) and with other features of the calculations (i.e., pseudopotential, LAPW, etc). As described above, the BZW method is applicable in most computations that utilize the LCAO formalism. The LCAO program package we employed in this work was developed many years[31–33] before the introduction of the BZW method in 1998. We provide below computational details germane to a replication of our calculations.

Zinc-blende InN is a member of the III-V family. The atomic wave functions of the ionic states of In^{1+} and N^{1-} were obtained from self-consistent *ab initio* calculations. The radial parts of the atomic wave functions were expanded in terms of Gaussian functions. A set of even-tempered Gaussian exponents was employed for In with a minimum of 0.1400 and a maximum of 0.2300×10^6, with 16 Gaussian functions for the *s* and *p* states and 14 for the *d* states of In^{1+}. The two largest exponents were not included in the description of the *d* state. Similarly, a set of even-tempered Gaussian exponents was utilized to describe N^{1-}, with a minimum of 0.1242 and a maximum of 0.1365×10^5. Both the *s* and *p* functions were expanded in terms of 13 Gaussian orbitals. The minimal basis set comprised atomic orbitals representing In^{1+} (*1s2s2p3s3p3d4s4p4d5s5p*) and N^{1-} (1s2s2p). A mesh of 28*k* points in the irreducible Brillouin zone, with proper weights, was used in the self-consistent iterations. The computational error for the valence charge was about −0.001 449 79 for 36 electrons. The self-consistent potentials converged to a difference around 10^{-5} after about 60 iterations.

TABLE III. Eigenvalues (eV), along high symmetry points, for zinc-blende indium nitride (*c*-InN), as obtained from LDA-BZW calculation for $a = 4.98$ Å. The Fermi energy −0.216 58 eV is set to zero the table.

L	Γ	X	K
−15.5977	−14.8586	−15.7269	−15.6720
−14.7642	−14.8586	−14.7370	−14.7084
−14.7642	−14.8586	−14.5160	−14.5781
−14.4583	−14.5212	−14.5160	−14.5685
−14.4583	−14.5212	−14.4279	−14.4714
−11.7856	−14.3473	−11.3252	−11.2093
−5.7063	0.0000	−4.8350	−4.6807
−0.8675	0.0000	−2.2907	−3.4730
−0.8675	0.0000	−2.2907	−1.8515
4.1748	0.7383	4.2140	5.6870
8.5382	9.9148	7.1020	7.3237
10.8738	9.9148	12.1018	10.7467
10.8738	9.9148	12.1018	11.8177

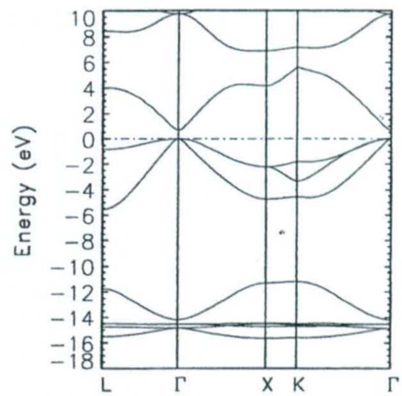

FIG. 1. Calculated LDA-BZW band structure of zinc-blende Indium Nitride (*c*-InN) at the theoretical equilibrium lattice constant of 5.017 Å, as obtained with BZW optimal basis set. The Fermi level (−0.216 87 eV) is set to zero in the figure.

III. RESULTS AND DISCUSSIONS

Table I shows our calculated, theoretical equilibrium band gap of 0.65 eV, at a lattice constant of 5.017 Å, and the value of 0.74 eV at an experimental lattice constant of 4.98 Å. Tables II and III contain the calculated energies, at some high symmetry points in the Brillouin zone, for the two lattice constants given above. Figures 1–3 exhibit the energy bands, for the theoretical equilibrium lattice constant (5.017 Å), and the related total (DOS) and partial (pDOS) densities of states. The curve of the total energy versus the lattice constant is shown in Fig. 4.

The lack of experimental data, except for the lattice constant, precludes an extensive discussion of these results. Our predicted equilibrium lattice constant is within 0.6% from

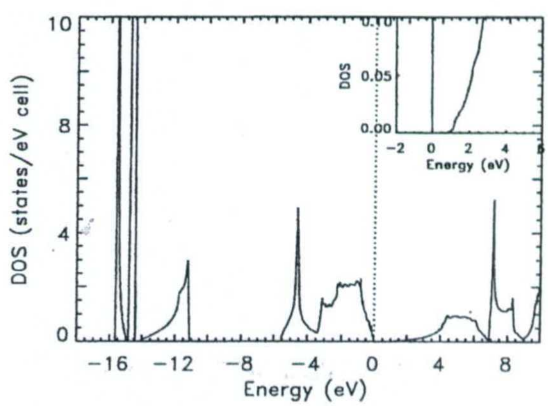

FIG. 2. Total DOS for zinc-blende indium nitride (*c*-InN) as obtained with the bands shown in Fig. 1. The inset illustrates our definition of a "practical band gap."

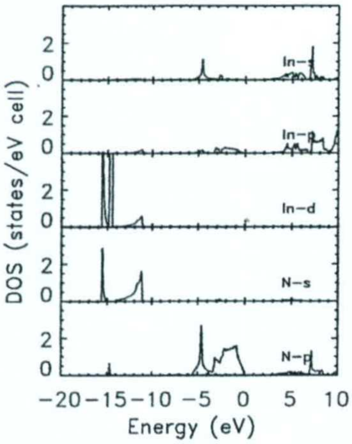

FIG. 3. pDOS for zinc-blende indium nitride (c-InN) as obtained with the bands shown in Fig. 1. The dominance of nitrogen p at the top of the valence band is obvious in this graph.

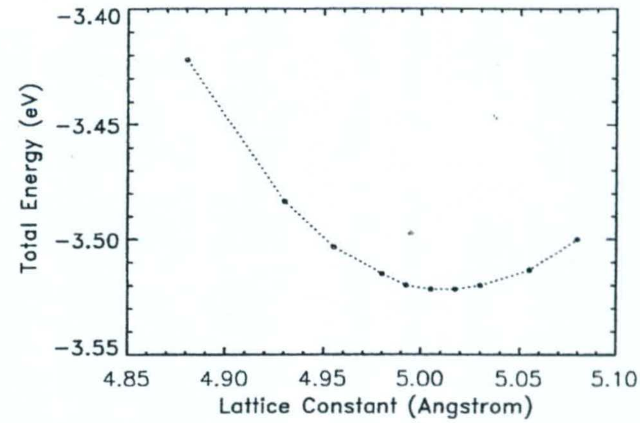

FIG. 4. Total energy of (c-InN) vs the lattice constant. The total energy at the equilibrium lattice constant of 5.017 Å is 1949.4215 eV.

the latest experimental one of 4.986 Å. Our calculated bulk modulus of 145 GPa is close to the results from some other LDA calculations[10,11] and disagrees with findings around 120 GPa from GGA calculation[11,13] as shown in Table I. The tables for the calculated energies are expected to provide useful comparisons for future experimental investigations. Our calculated LDA-BZW band structure is drastically different from the findings of most of the previous calculations—as far as the unoccupied bands are concerned. The large differences between our calculated band gaps and previous LDA results in Table I are a direct consequence of the differences between the respective *unoccupied* bands.

The empirical pseudopotential (EMP) result[22] of 0.592 eV is relatively close to our findings of 0.65 and 0.74 eV. We cannot draw much fundamental significance from this fact, however, given that this EMP result was obtained using model potential parameters whose derivation entailed fitting to data that included a band gap of 0.59 eV. For the purposes of application, however, this closeness portends much importance. Indeed, we expect potential parameters derived from fitting to our data to lend themselves to credible and practical descriptions of electronic, optical, elastic, and structural properties of materials. This assertion is partly supported by the versatility and relative ease of empirical pseudopotential calculations.

As in the case of w-InN,[23] our results do not show any indication of an overestimation of the p-d repulsion by LDA potentials. This overestimation was believed[10] to be the source of the very small or negative band gaps by pushing the top of the valence band, dominated by p states, to higher energies. According to our findings, it is rather the extra lowering of the bottom of the conduction band that produces LDA band gaps that are negative or very small[23,25] if LCAO type computations do not utilize the BZW approach to avoid it while ensuring the adequacy (or convergence) of the basis set for the description of occupied states. In fact, the basic derivation of the ground state theory that is the original density functional theory[34,35] implicitly suggests such an approach, notwithstanding the need to account for the redistribution of electrons in molecular to solid environments with judicious polarization and diffuse orbitals.[36]

As per their definition, effective masses provide a measure of the quality (i.e., curvature) of band structures. Our LDA-BZW calculations found electron effective masses, at the bottom of the conduction band, of $0.065m_0$, $0.066m_0$, and $0.066m_0$ in the Γ-L, Γ-X, and Γ-K directions, respectively, for the equilibrium lattice constant. For a lattice constant of 4.98 Å, the corresponding effective masses for the electrons are $0.076m_0$, $0.073m_0$, and $0.073m_0$ in the Γ-L, Γ-X, and Γ-K directions, respectively. Our calculated, equilibrium, electron effective masses are very close to the $0.066m_0$ from the EMP calculations of Fritsch, Schmidt, and Grundmann.[22] This agreement supports our comment above relative to the potential use of EMP calculations when the potential parameters are derived in part by fitting to LDA-BZW results.

IV. CONCLUSION

In lieu of a conclusion, we contend that our *ab initio*, self-consistent LDA-BZW calculations have predicted electronic, structural, and elastic properties of cubic InN (c -InN) in the zinc-blende structure. It is hoped that experimental investigations will follow in the near future. It emerges from this work that theoretical efforts should be directed to the determination of actual limitations of LDA and of other approaches as opposed to echoing the chorus now known to be untenable, as per the physical interactions, and that ascribes to LDA a woeful underestimation of band gaps that is, as per the Rayleigh theorem, straightforwardly a consequence of a basis set and variational effect.

ACKNOWLEDGMENTS

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[1]J. W. Orton and C. T. Foxon, Rep. Prog. Phys. 1 (1998).
[2]O. Ambacher, J. Phys. D **31**, 2653 (1998).
[3]A. G. Bhuiyan, A. Hashimoto, and A. Yamamoto, J. Appl. Phys. **94**, 2779 (2003).

[4]I. Vurgaftman and J. R. Meyer, J. Appl. Phys. **94**, 3675 (2003).
[5]J. Wu *et al.*, Appl. Phys. Lett. **80**, 3967 (2002).
[6]A. Yamamoto, Y. Yamauchi, M. Ohkubo, and A. Hashimoto, J. Cryst. Growth **174**, 641 (1997).
[7]A. Tabata *et al.*, Appl. Phys. Lett. **74**, 362 (1999).
[8]D. Chandrasekhar, David J. Smith, S. Strite, M. E. Lin, and H. Morkoc, J. Cryst. Growth **152**, 135 (1995).
[9]V. Cimalla *et al.*, Appl. Phys. Lett. **83**, 3468 (2003).
[10]F. Bechstedt and J. Furthmüller, J. Cryst. Growth **246**, 315 (2002).
[11]M. Fuchs, J. L. F. Da Silva, C. Stampfi, J. Neugebauer, and M. Scheffler, Phys. Rev. B **65**, 245212 (2002).
[12]L. E. Ramos, L. K. Teles, L. M. R. Scolfaro, J. L. P. Castineira, A. L. Rosa, and J. R. Leite, Phys. Rev. B **63**, 165210 (2001).
[13]C. Stampfl and C. G. Van de. Walle, Phys. Rev. B **59**, 5521 (1998).
[14]M. Stäedele, J. A. Majewski, P. Vogl, and A. Görling, Phys. Rev. Lett. **79**, 2089 (1997).
[15]D. Vogel, P. Krüger, and J. Pollmann, Phys. Rev. B **55**, 12836 (1997).
[16]M. van Schilfgaarde, A. Sher, and A. B. Chen, J. Cryst. Growth **178**, 8 (1997).
[17]K. Kim, Walter R. L. Lambrecht, and B. Segall, Phys. Rev. B **53**, 16310 (1996).
[18]A. F. Wright and J. S. Nelson, Phys. Rev. B **51**, 7866 (1995).
[19]N. E. Christensen and I. Gorczyca, Phys. Rev. B **50**, 4397 (1994).
[20]M. E. Sherwin and T. J. Drummond, J. Appl. Phys. **69**, 8423 (1991).
[21]P. E. Van Camp, V. E. Van Doren, and J. T. Devreese, Phys. Rev. B **41**, 1598 (1990).
[22]D. Fritsch, H. Schmidt, and M. Grundmann, Phys. Rev. B **69**, 165204 (2004).
[23]D. Bagayoko and L. Franklin, J. Appl. Phys. (submitted).
[24]D. Bagayoko, G. L. Zhao, J. D. Fan, and J. T. Wang, J. Phys.: Condens. Matter **10**, 5645 (1998).
[25]G. L. Zhao, D. Bagayoko, and T. D. Williams, Phys. Rev. B **60**, 1563 (1999).
[26]D. Bagayoko, Int. J. Quantum Chem. **17**, 527 (1983).
[27]D. M. Ceperley and B. J. Alder, Phys. Rev. Lett. **45**, 566 (1980).
[28]J. P. Perdew and A. Zunger, Phys. Rev. B **23**, 5048 (1981).
[29]D. Bagayoko, G. L. Zhao, and S. Hasan, in *A Mathematical Solution of the Band Gap Problem*, in Contemporary Problems In Mathematical Physics, edited by Jan Govaerts, M. Norbert Hounkonnou, and Alfred Z. Msezane (World Scientific, London, 2002), 222–232.
[30]G. L. Zhao, D. Bagayoko, and E. G. Wang, Phys. Rev. B **69**, 1 (2004).
[31]P. J. Feibelman, J. A. Appelbaum, and D. R. Hamann, Phys. Rev. B **20**, 1433 (1979).
[32]B. N. Harmon, W. Weber, and D. R. Hamann, Phys. Rev. B **25**, 1109 (1982).
[33]G. L. Zhao, T. C. Leung, B. N. Harmon, M. Keil, M. Muller, and W. Weber, Phys. Rev. B **40**, 7999 (1989).
[34]P. Hohenberg and W. Kohn, Phys. Rev. **136**, B864 (1964).
[35]W. Kohn and L. J. Sham, Phys. Rev. **140**, A1133 (1965).
[36]D. Bagayoko, Pui-Man, N. Brener, and J. Callaway, Phys. Rev. B **54**, 12184 (1996).

Effective masses of charge carriers in selected symmorphic and nonsymmorphic carbon nanotubes

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We performed *ab initio*, self-consistent calculations for the electronic structure of selected semiconducting carbon nanotubes in the symmorphic and nonsymmorphic groups. We employed a real space approach in the linear combination of atomic orbital formalism. We utilized a nonlocal density-functional potential in the generalized gradient approximation. We present the electronic structure and effective masses of charge carriers in symmorphic nanotubes that include (10,0), (13,0), (17,0), and (22,0), and the nonsymmorphic tubes (8,4) and (10,5). For nonsymmorphic carbon nanotubes (8,4) and (10,5), the top of the highest occupied valence band and the bottom of the lowest unoccupied conduction band are not at the Γ point, but at about $\pm 0.1(1,0,0)\pi/L$, where the tubule axis is defined as the $(1,0,0)$ direction. The band gaps in the nonsymmorphic (8,4) and (10,5) can be direct for transitions at $+0.1(1,0,0)\pi/L$ or $-0.1(1,0,0)\pi/L$, and can also be indirect for transitions from $+0.1(1,0,0)\pi/L$ to $-0.1(1,0,0)\pi/L$, or vice versa.

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I. INTRODUCTION

Single-walled carbon nanotubes (SWCNT's) are potentially ideal materials for building electronic devices at nanometer scales.[1–3] Understanding their electronic properties is essential for large scale applications. However, such materials are usually too small for many conventional measurements. Predictive calculations with certain reliability are indispensable to obtain their physical properties.

In the last several years, tight-binding calculations have been extensively used to study the electronic structure of carbon nanotubes.[4] Tight-binding approximations based on the symmetry of the honeycomb lattice of graphite predicted that SWCNT's could be semiconducting or metallic depending on their index (n,m). Although the tight-binding approximation is a useful tool to estimate the basic electronic structure of SWCNT's, the curvature-related effects and the hybridization of different electron states of graphite could lead to the electronic properties of SWCNT's that are substantially different from that of the tight-binding calculations. Zigzag $(n,0)$ (where n is a multiple of 3) SWCNT's which were predicted to be metallic from tight-binding calculations were found to have small energy gaps at their Fermi level.[5–8]

Ab initio quantum calculations, which do not have these deficiencies, can be used to obtain the electronic properties of individual SWCNT's. Prior *ab initio* density-functional calculations were mostly applied to the studies of the electronic structure of symmorphic SWCNT's.[9–16] Nonsymmorphic SWCNT's, which are encountered more often in experiments than the symmorphic ones such as zigzag and armchair SWCNT's, need attention. Nonsymmorphic SWCNT's generally involve a large number of atoms in their unit cells. For example,, nonsymmorphic tubes (8,4) and (10,5) have 112 and 140 atoms in their unit cells, respectively. The large number of atoms in the unit cells presents some technical challenges for *ab initio* calculations. Reich *et al.* recently reported the electronic band structure of some chiral nanotubes in nonsymmorphic group.[17] They used the local-density approximation (LDA) and nonlocal normconserving pseudopotentials. In their calculation, the valence electrons were described by localized pseudoatomic orbitals with a double ζ singly polarized basis set.

The calculation or prediction of the effective masses of charge carriers in SWCNT's requires a reliable result of the dispersions of the electron energy bands. Although, the electron energy bands from the tight-binding approximation can be adjusted to agree approximately with the results of the *ab initio* calculations. Such adjustment of the tight-binding parameters cannot lead to a prediction of the effective masses of charge carriers in SWCNT's. In this work, we report the all electron and full potential *ab initio* calculations of the effective masses of charge carriers and other related properties of some symmorphic and nonsymmorphic SWCNT's. We utilized *ab initio*, nonlocal density-functional calculations in the generalized gradient approximation (GGA).[18] We used the formalism of the linear combination of atomic orbitals (LCAO) in real space. We describe our method in Sec. II. Section III presents our results for selected symmorphic and nonsymmorphic nanotubes, in that order. We utilized the calculated results of the electronic energy bands to predict the effective masses of charge carriers (electrons and holes) in selected semiconducting carbon nanotubes. A brief conclusion is provided in Sec. IV.

II. METHOD

Our calculations of the electronic structure of SWCNT's are based on the density-functional theory of Hohenberg-Kohn and Kohn-Sham.[19,20] The Schrodinger-like equations (also known as the Kohn-Sham equations) of many electron system[19–21] are

$$\left\{-\frac{\hbar^2}{2m}\nabla^2-\sum_{lm}\frac{e^2Z_m}{|\vec{r}-\vec{\tau}_m-\vec{R}_l|}+e^2\int\frac{\rho(\vec{r}')}{|\vec{r}-\vec{r}'|}dv'+V_{xc}\right\}\Psi_{\vec{k}i}$$
$$=E_{\vec{k}i}\Psi_{\vec{k}i}, \tag{1}$$

where $E_{\vec{k}i}$ and $\Psi_{\vec{k}i}$ are the eigenenergy and eigenfunction of the ith electronic state at the $\vec{k}$ point in the Brillouin zone; $\vec{\tau}_m$ and Z_m are the position and the nuclear charge of the mth ion; $\vec{R}_l$ is a translational vector; V_{xc} is the exchange-correlation potential of the many-electron system. We employed nonlocal density-functional calculations for the exchange-correlation energies and potentials in the generalized gradient approximation that was developed by Perdew and Wang.[18] In the Kohn-Sham equations, the electron density $\rho(\vec{r})$ depends on the wave functions $\Psi_{\vec{k}i}$ of the occupied electron states, i.e.,

$$\rho(\vec{r})=\sum_{\vec{k}i}f_{\vec{k}i}|\Psi_{\vec{k}i}|^2, \tag{2}$$

where $f_{\vec{k}i}$ is the Fermi distribution function.

In the LCAO method,[22–27] we expand the electronic eigenfunction $\Psi_{\vec{k}i}$ of the many-atom system as a linear combination of the atomic wave functions. We calculated the atomic wave function using a separate computer program that employed *ab initio* density-functional computations. We further expanded the atomic wave functions as a linear combination of Gaussian orbitals in real space. In the calculation of the atomic orbitals of carbon, we included 13 Gaussian orbitals. We employed a set of even-tempered Gaussian exponentials with a minimum of 0.124 and a maximum of 0.1365×10^5 in atomic unit, in the calculation for the carbon atom. The electron densities were also expressed as a linear combination of Gaussian functions in real space. The computation for the exchange-correlation potentials was done in real space using a mesh of points around each atom. The numbers of mesh points per atomic site varied from 3150 to 3250, depending on the local structure of the atom. We solved the Kohn-Sham equations by a self-consistent iteration procedure. The self-consistent potentials converged to a difference around 10^{-5} after an average of about 40 iterations.

III. RESULTS

A. Symmorphic zigzag carbon nanotubes

We calculated the electronic structure of selected symmorphic SWCNT's that included semiconducting zigzag tubes (10,0), (13,0), (17,0), and (22,0). The diameters of these symmorphic SWCNT's are 7.83, 10.18, 13.31, and 17.23 Å, respectively. There are a relatively large number of atoms in the nanotube unit cells. SWCNT's (10,0), (13,0), (17,0), and (22,0) have 40, 52, 68, and 80 carbon atoms in their unit cells, respectively. Their unit cell lengths in the direction of the nanotube axis are the same at 4.26 Å.

We first tested the convergency of the electronic structure calculations with respect to the size of the basis sets of atomic orbitals.[28] As a demonstration, we present the following calculated results for SWCNT (10,0). We first carried out completely self-consistent calculation for SWCNT (10,0) using a minimal LCAO basis set that included atomic orbitals of C($1s$ $2s$ $2p$). We then repeated the self-consistent calculation using an augmented basis set that also includes the atomic orbital of C($3s^0$). In the self-consistent calculations, we took C($1s$) as a core state. We then plotted the resulting energy bands from these two distinct self-consistent calculations. We observed that the occupied and unoccupied bands from the two calculations differ considerably.

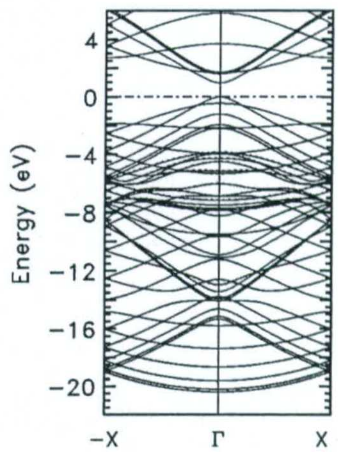

FIG. 1. The comparison of the calculated electron energy bands of SWCNT (10,0) from calculations III and IV. Calculation III utilized the atomic orbitals of C($1s2s3s$ $2p3p$). Calculation IV included an additional orbital of C($4s$). The solid lines represent the results of Calculation III; the dashed lines show the results from Calculation IV.

The next step was to repeat our procedure, for a third time, with a new basis set that also included C($3p^0$) orbital. The results of the third calculation and of the second calculation are compared. The calculated electron energy bands of the two differ slightly. We then repeated the procedure for a fourth time to include C($4s^0$) in the calculation. The results of the fourth calculation (dashed lines) and of the third calculation (solid lines) are shown in Fig. 1. The calculated electron energy bands from the third calculation do not have a noticeable difference from that of the fourth calculation. The average difference between the occupied energy bands from the two calculations in Fig. 1 is at the order of 1 mRy. The third calculation (the solid lines of Fig. 1) which includes the atomic orbitals of C($1s$ $2s$ $3s$ $2p$ $3p$) leads to sufficiently converged electron energy bands of SWCNT (10,0) with respect to the size of the basis set. We chose the top of the highest occupied band at the Γ point as the zero of the energy.

From the results in Fig. 1, we conclude that SWCNT (10,0) has a direct band gap of 0.95 eV at the Γ point. The highest occupied valence band and the lowest unoccupied conduction band of symmorphic zigzag SWCNT (10,0) are doubly degenerate near the Γ point. We did not include the relativistic effect in these calculations. Our calculated band-gap energy of 0.95 eV for SWCNT (10,0) is very close to the ones obtained by other *ab initio* calculations using the density-functional calculations and to experimental measurements. Mazzoni and Chacham[28] obtained a band gap of

0.92 eV for zig-zap SWCNT (10,0), utilizing the SIESTA program that implemented density-functional theory, within the generalized gradient approximation, for the exchange-correlation potential and norm-conserving pseudopotentials. Our calculated band gap also agrees well with the first-principles LDA calculations performed by Mintmire, Robertson, and White.[29] We also performed LDA calculations for the electronic structure of SWCNT (10,0) and found a direct band gap at the Γ point that is smaller than that from our GGA calculations by about 0.003 eV. Odom *et al.* performed the measurements using the scanning tunneling microscopy for various carbon nanotubes and presented the band-gap energies in a range of 0.9–0.96 eV for tube diameters around 7.8 Å.[30] The tube diameter of SWCNT (10,0) is 7.83 Å.

We utilized the results of the third calculation to compute the total energies of SWCNT (10,0) at the relaxed structures of various C-C bond lengths. The stable structure of SWCNT (10,0) was determined from the minimization of the total energies. Two of the three C-C bond lengths in SWCNT (10,0) are the same at 1.416 Å and one of them is 1.420 Å. These calculated bond lengths agree well with the C-C bond length of 1.42 Å (Ref. 31) in graphite and with the commonly observed C-C bond length in carbon nanotubes. We also compared the GGA results with those of our LDA calculations. Our LDA calculations found relatively smaller C -C bond lengths in SWCNT (10,0). Two of the C-C bond lengths are 1.39 Å and one is 1.40 Å.

From these test calculations as discussed above and the comparisons of the calculated results of various methods and that with the results of experimental measurements, we can conclude that the electronic energy bands of SWCNT (10,0) as presented in Fig. 1 are reasonably reliable. We can further use the calculated electronic structure to obtain other physical quantities. The effective mass of charge carriers in semiconductors is an important physical quantity that is used in analysis of the electron transport properties, particularly in the effective-mass approximation.[32–35] In these previous analyses, the effective masses of charge carriers in carbon nanotubes were used as adjustable parameters. In this work, we utilized the results of the *ab initio* calculations to obtain the effective masses of charge carriers in SWCNT's. The calculated effective mass of charge carriers near the top of the valence band, which are referred to as holes, is $0.1m_0$, where m_0 is the free electron mass. The effective mass of charge carriers (electrons) near the bottom of the conduction band is also $0.1m_0$, which nearly is the same as that of the effective mass of holes. This property is different from that of many other semiconductors in which the effective masses (or band masses) of holes are usually larger than that of electrons. The closeness of the effective masses of holes to those of the electrons in SWCNT (10,0) is attributed to its electron energy bands. The dispersions of the highest occupied valence band (HOVB) and of the lowest unoccupied conduction band (LUCB) in SWCNT (10,0) are nearly symmetric around the Γ point. One can see this feature from Fig. 1. Other valence and conduction bands away from the Fermi level (E_F) do not have this symmetry property.

We used the same computational techniques to calculate the electronic structure of other SWCNT's that have relatively larger diameters and involve many more atoms in their unit cells. They include SWCNT's (13,0), (17,0), and (22,0) which have 52, 68, and 88 atoms in their unit cells, respectively. We present the calculated electron energy bands of these SWCNT's in Figs. 2–4. These symmorphic zigzag SWCNT's are direct band-gap semiconductors. The band-gap energies of SWCNT (13,0), (17,0), and (22,0) are 0.75, 0.54, and 0.44 eV, respectively. The HOVB and LUCB of these zigzag SWCNT's are doubly degenerate near the Γ point, as was the case of (10,0). Even though these SWCNT's have different diameters, the widths of their valence bands below E_F are approximately the same. This width is 20.4 eV. By valence bands, in this contest, we mean the occupied bands as shown in the figures of the band structures.

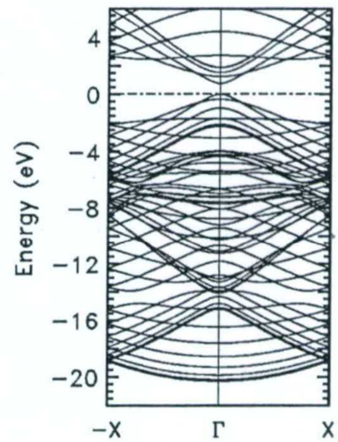

FIG. 2. The calculated electron energy bands of SWCNT (13,0).

We also calculated the effective masses of charge carriers in SWCNT's (13,0), (17,0), and (22,0). The calculated results are presented in Table I. $E_v^{(1)}$ in Table I refers to the first valence band near the Fermi level (E_F), whereas $E_c^{(1)}$ refers to the first conduction bands from E_F. In Table I, E_m is the energy (in eV) of the top of the valence band or of the bottom of the conduction band. The energy of the top of the first valence band $E_v^{(1)}$ is chosen to be zero in Table I. "Deg" refers to the degeneracy of the bands. As in the case of

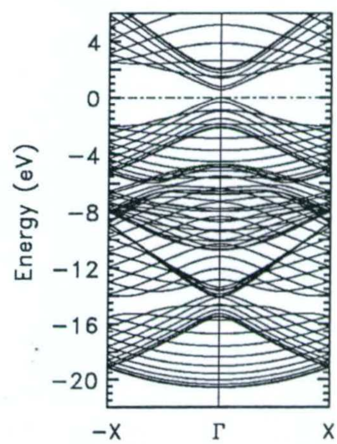

FIG. 3. The calculated electron energy bands of SWCNT (17,0).

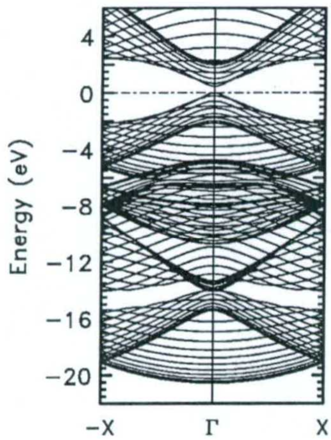

FIG. 4. The calculated electron energy bands of SWCNT (22,0).

SWCNT (10,0), the effective masses of electrons around the bottom of the conduction bands in these SWCNT's are nearly the same as that of holes around the top of the valence bands. In SWCNT (13,0), the first conduction band above E_F is symmetric to the first valence band below E_F as presented in Fig. 2. The second conduction band above E_F is nearly symmetric to the second valence band below E_F, but the separation of the first two conduction bands is slightly larger than that of the first two valence bands by about 0.05 eV at the Γ point. In SWCNT's (17,0) and (22,0), the first two conduction bands above E_F are symmetric to the first two valence bands below E_F as presented in Figs. 3 and 4. Other electron bands away from E_F do not have the symmetry property.

TABLE I. The calculated effective masses (m^*) of charge carriers in various 1D SWCNT's.

Band	E_m (eV)	Deg	m^* (m_0)
SWCNT	(10,0)		
$E_v^{(1)}$	0.0	2	0.10
$E_c^{(1)}$	0.95	2	0.10
SWCNT	(13,0)		
$E_v^{(1)}$	0.0	2	0.09
$E_c^{(1)}$	0.75	2	0.09
SWCNT	(17,0)		
$E_v^{(1)}$	0.0	2	0.11
$E_c^{(1)}$	0.54	2	0.11
SWCNT	(22,0)		
$E_v^{(1)}$	0.0	2	0.057
$E_c^{(1)}$	0.44	2	0.056
SWCNT	(8,4)		
$E_v^{(1,2)}$	0.0	1	0.13
$E_c^{(1,2)}$	0.96	1	0.13
SWCNT	(10,5)		
$E_v^{(1,2)}$	0.0	1	0.11
$E_c^{(1,2)}$	0.74	1	0.11

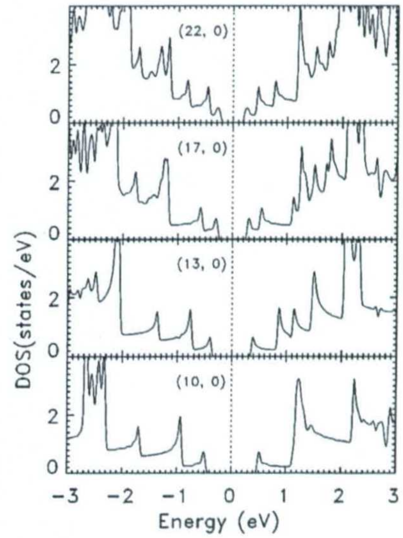

FIG. 5. The calculated electron density of states of SWCNT's (10,0), (13,0), (17,0), and (22,0).

We calculated the electron densities of states (DOS) of the one-dimensional (1D) nanotubes using the following formulas:[36]

$$D(E) = \frac{1}{N}\sum_{\vec{k}i} \delta(E - E_{\vec{k}i}), \tag{3}$$

where $E_{\vec{k}i}$ is the energy of the ith electron band at the $\vec{k}$ point in the irreducible Brillouin zone; N is the total number of $\vec{k}$ points. In our calculations of DOS, the δ function in Eq. (3) was replaced with a Gaussian function,

$$\delta(E) \approx \frac{1}{\Delta\sqrt{\pi}}\exp\left[-\left(\frac{E}{\Delta}\right)^2\right] \tag{4}$$

We used $\Delta = 2$ mRy (or 0.027 eV) in these calculations. We calculated the DOS over an energy range of 30 eV and used 3000 points. We utilized the *ab initio* computations to obtain the electronic energy levels at 40 k points in the irreducible Brillouin zone of 1D SWCNT's. Additionally, we implemented a linear interpolation method to calculate the electron energy levels at other ten k points between any two k points of the *ab initio* results. We then included a total of about 400 k points in the irreducible Brillouin zone of 1D SWCNT's for the calculations of the DOS. The calculated results of the DOS of zigzag SWCNT's are presented in Fig. 5. The zero of the energy in Fig. 5 is set at the middle of the band gaps. The calculated densities of states in Fig. 5 show Van Hove singularities (the peaks) at the extremal points of energy bands. Figure 5 shows that the location and the relative height of the first peak below the Fermi level are nearly symmetric to that of the first peak above the Fermi level in the zigzag SWCNT's. These results are consistent with the data in Table I where the effective masses of holes in these SWCNT's are nearly the same as those of the corresponding electrons.

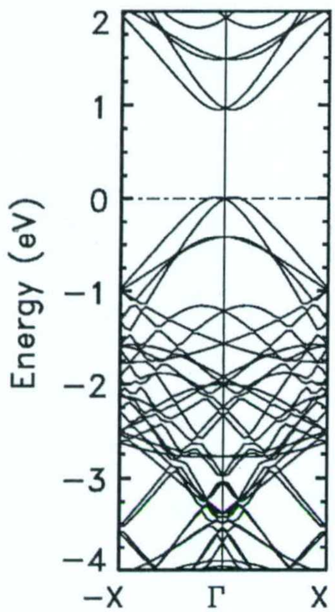

FIG. 6. The calculated electron energy bands of SWCNT (8,4).

B. Nonsymmorphic carbon nanotubes (8,4) and (10,5)

We calculated the electronic structure of nonsymmorphic SWCNT's (8,4) and (10,5), utilizing the nonlocal density-functional calculations in the generalized gradient approximation. The length of the unit cells of these two SWCNT's along the tubule axis is 11.27 Å. The diameters of these nanotubes are 8.29 Å for (8,4) and 10.36 Å for (10,5). There are 112 and 140 carbon atoms in the unit cells of SWCNT's (8,4) and (10,5), respectively.

The calculated electron energy bands of nonsymmorphic SWCNT's (8,4) and (10,5), are presented in Figs. 6 and 7. Unlike the energy bands of symmorphic zigzag SWCNT's,

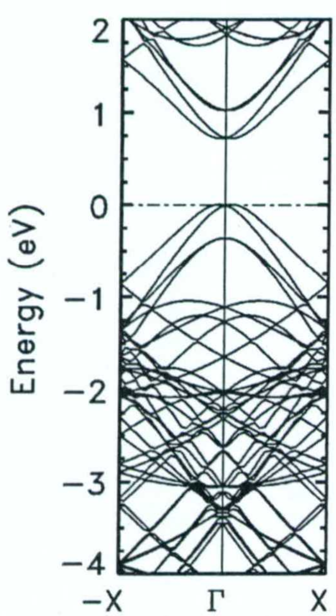

FIG. 7. The calculated electron energy bands of SWCNT (10,5).

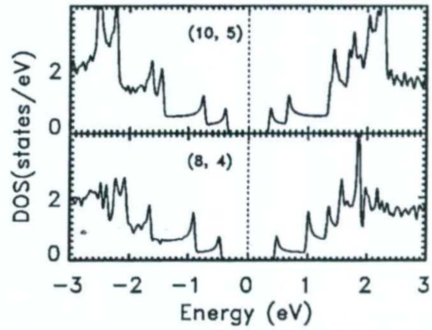

FIG. 8. The calculated electron density of states of SWCNT (8,4) and (10,5).

the top of the HOVB and the bottom of the LUCB of nonsymmorphic (8,4) and (10,5) are not at the Γ point, but at about $\pm 0.1(1,0,0)\pi/L$. Both bands are nondegenerate. We may view the HOVB and LUCB of (8,4) and (10,5) as if the doubly degenerate bands near the Fermi level of symmorphic zigzag SWCNT split off from the Γ point symmetrically and form the two nondegenerate bands of nonsymmorphic SWCNT's (8,4) and (10,5). Nonsymmorphic SWCNT's (8,4) and (10,5) have band-gap energies of 0.96 and 0.74 eV, respectively. The band gaps in nonsymmorphic SWCNT's (8,4) and (10,5) can be direct for transitions at $+0.1(1,0,0)\pi/L$ or $-0.1(1,0,0)\pi/L$. The band gaps in SWCNT's (8,4) and (10,5) can also be indirect for transitions from $+0.1(1,0,0)\pi/L$ to $-0.1(1,0,0)\pi/L$, or vice versa. The energies of the direct and indirect band gaps are the same. These are the first cases of semiconductors that present such a peculiar property, to our knowledge.

Optical measurements of the low-energy excitations in SWCNT's (8,4) and (10,5) should reveal the direct band gaps as well as the indirect band gaps. However, the indirect absorption process has to be assisted through the absorption or excitations of phonons or others quasiparticles. The probability of indirect transitions will generally be lower than that of direct excitations. Since the phonon excitations are generally temperature dependent, the indirect transitions in SWCNT's (8,4) and (10,5) will present a temperature dependent behavior.

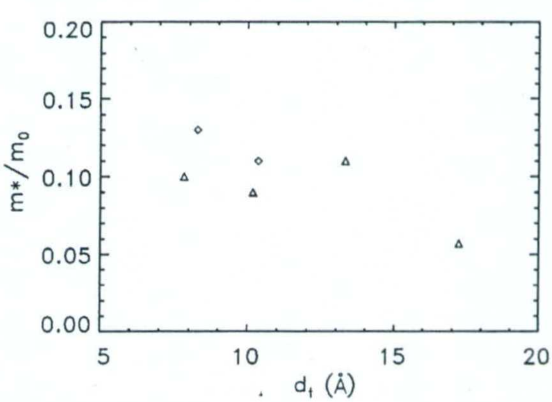

FIG. 9. The effective masses m^* of charge carriers of the semiconducting carbon nanotubes as a function of the tube diameters d_t, where m_o is the free electron mass.

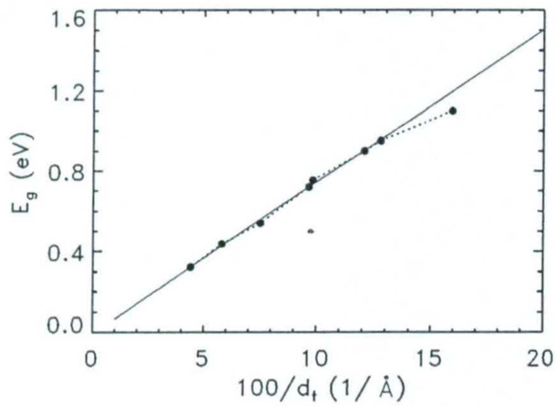

FIG. 10. The calculated band-gap energy E_g of semiconducting SWCNT's as a function of $100/d_t$, where d_t (in Å) is the diameter of SWCNT.

We also calculated the electron density of states of (8,4) and (10,5) that are presented in Fig. 8. The zero of the energy in Fig. 8 is set at the middle of the band gaps. The calculated densities of states in Fig. 8 show Van Hove singularities at the extremal points of energy bands. As in the case of zigzag SWCNT's, the locations and the relative heights of the first peaks below and above the Fermi level are nearly symmetric in these nonsymmorphic SWCNT's. So the effective masses of holes will be similar to that of the electrons in (8,4) and (10,5). The calculated effective masses of charge carriers (including electrons and holes) in (8,4) and (10,5) are 0.13 and $0.11m_0$, respectively, and are listed in Table I.

We summarize the effective masses of charge carriers of the semiconducting carbon nanotubes as a function of the tube diameters in Fig. 9. The open triangles in Fig. 9 represent the data for the symmorphic SWCNT's (10,0), (13,0), (17,0), and (22,0); the open diamonds represent the results for nonsymmorphic SWCNT's (8,4) and (10,5). Although the data points do not fall on a simple line, the general trend is that the effective masses of charge carriers decrease as the tube diameters increase. At comparable tube diameters, the effective masses of charge carriers of nonsymmorphic SWCNT's are slightly larger than those of symmorphic ones.

Finally, we present the calculated band-gap energies, E_g, of the semiconducting carbon nanotubes as a function of $100/d_t$ in Fig. 10. The data include symmorphic zigzag SWCNT's and nonsymmorphic SWCNT's (8,4) and (10,5). For the SWCNT's with relatively large diameters, the band-gap energy is a linear function of $100/d_t$. This result is consistent with the findings of tight-binding calculations by Mintmire, Robertson, and White.[29] Utilizing the Huckel tight-binding calculations, they obtained the relation, $E_g = \gamma_0 a_{c-c}/d_t$, where a_{c-c} is the nearest-neighbor C-C distance on a graphite sheet, and γ_0 is a tight-binding parameter. However, the band-gap energies of the SWCNT's whose diameters are smaller than 7.5 Å, do not follow the above relation. The deviation from the tight-binding calculations is primarily due to the curvature effect of carbon nanotubes.

IV. CONCLUSION

We successfully performed *ab initio* calculations for the electronic structure of selected symmorphic and nonsymmorphic carbon nanotubes. These carbon nanotubes are semiconductors. The large numbers of atoms in the unit cells of nonsymmorphic carbon nanotubes (8,4) and (10,5) lead to significant computational efforts. We employed a real space approach in the LCAO formalism. We presented the effective masses of charge carriers in these carbon nanotubes. The calculated electronic structures indicate that the symmorphic zigzag SWCNT's (10,0), (13,0), (17,0), and (22,0) are direct band-gap semiconductors. For nonsymmorphic SWCNT's (8,4) and (10,5), the top of the highest occupied valence band and the bottom of the lowest unoccupied conduction band are not at the Γ point, but at about $\pm 0.1(1,0,0)\pi/L$. The band gaps in nonsymmorphic SWCNT (8,4) and (10,5) can be direct for transitions at $+0.1(1,0,0)\pi/L$ or $-0.1(1,0,0)\pi/L$, and can also be indirect for transitions from $+0.1(1,0,0)\pi/L$ to $-0.1(1,0,0)\pi/L$ or vice versa. The effective masses of holes are nearly the same as those of the electrons in these SWCNT's.

ACKNOWLEDGMENTS

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[1] D. Voss, Mit's Technol. Rev. **102**, 55 (1999).

[2] M. S. Dresselhaus, G. Dresselhaus, and P. C. Eklund, *Science of Fullerenes and Carbon Nanotubes* (Academic Press, New York, 1996), Chap. 19.

[3] Some of the experimental studies on carbon nanotubes also include, M. Bockrath, W. Liang, D. Bozovic, J. H. Hafner, C. M. Lieber, M. Tinkham, and H. Park, Science **291**, 283 (2001); M. Ouyan, J. L. Huang, C. L. Cheung, and C. M. Lieber, *ibid.* **291**, 97 (2001); T. W. Odom, J. L. Huang, P. Kim, and C. M. Lieber, J. Phys. Chem. B **104**, 2794 (2000); J. W. G. Wilder, L. C. Venema, A. G. Rinzler, R. E. Smalley, and C. Dekker, Nature (London) **391**, 59 (1998); P. Kim, T. W. Odom, J. L. Huang, and C. M. Lieber, Phys. Rev. Lett. **82**, 1225 (1999).

[4] Some of the tight-binding calculations for carbon nanotubes also include J. W. Mintmire, B. I. Dunlap, and C. T. White, Phys. Rev. Lett. **68**, 631 (1992); R. Saito, M. Fujita, D. Dresselhaus, and M. S. Dresselhaus, Appl. Phys. Lett. **60**, 2204 (1992); N.

Hamada, S. Sawada, and A. Oshiyama, Phys. Rev. Lett. **68**, 1579 (1992); C. T. White and J. W. Mintmire, Nature (London) **394**, 29 (1998); L. Yang and J. Han, Phys. Rev. Lett. **85**, 154 (2000).

[5]M. Ouyang, J. L. Huang, C. L. Cheung, and C. M. Lieber, Science **292**, 702 (2001).

[6]P. G. Collins, M. Arnold, M. Hersam, R. Martel, and Ph. Avouris, Phys. Rev. Lett. **86**, 3128 (2001).

[7]S. J. Tans, A. R. M. Verschueren, and C. Dekker, Nature (London) **393**, 49 (1998).

[8]L. Chico, V. H. Crespi, L. X. Benedict, S. G. Louie, and M. L. Cohen, Phys. Rev. Lett. **76**, 971 (1996).

[9]X. Blase, L. X. Benedict, E. L. Shirley, and S. G. Louie, Phys. Rev. Lett. **72**, 1878 (1994).

[10]J. W. Mintmire and C. T. White, Appl. Phys. A: Mater. Sci. Process. **67**, 65 (1998).

[11]R. J. Baierle, S. B. Fagan, R. Mota, A. J. R. da Silva, and A Fazzio, Phys. Rev. B **64**, 085413 (2001).

[12]J. L. Yang, H. J. Liu, and C. T. Chan, Phys. Rev. B **64**, 085420 (2001).

[13]G. Van Lier, C. Van Alsenoy, V. Van Doren, and P. Geerlings, Chem. Phys. Lett. **326**, 181 (2000).

[14]S. Han and J. Ihm, Phys. Rev. B **61**, 9986 (2000).

[15]J. C. Charlier, P. Lambin, and T. W. Ebbesen, Phys. Rev. B **54**, R8377 (1996).

[16]J. C. Charlier, X. Gonze, and J. P. Michenaud, Europhys. Lett. **29**, 43 (1995).

[17]S. Reich, C. Thomsen, and R. Ordejon, Phys. Rev. B **65**, 155411 (2002).

[18]J. P. Perdew and Wang Yue, Phys. Rev. B **33**, 8800 (1986); J. P. Perdew, Phys. Rev. B **33**, 8822 (1986); J. P. Perdew and A. Zunger, *ibid.* **23**, 5048 (1981).

[19]P. Hohenberg and W. Kohn, Phys. Rev. **136**, B864 (1964).

[20]W. Kohn and L. J. Sham, Phys. Rev. **140**, A1133 (1965).

[21]J. Callaway and N. H. March, *Solid State Physics*, edited by H. Ehrenreich, D. Turnbull, and F. Seitz (Academic Press, New York, 1984), Vol. 38, p. 135 and references therein.

[22]G. L. Zhao and M. E. Bachlechner, Phys. Rev. B **58**, 1887 (1998).

[23]D. Bagayoko, G. L. Zhao, J. D. Fan, and J. T. Wang, J. Phys.: Condens. Matter **10**, 5645 (1998).

[24]G. L. Zhao, D. Bagayoko, and T. D. Williams, Phys. Rev. B **60**, 1563 (1999).

[25]N. E. Brener, J. M. Tyler, J. Callaway, D. Bagayoko, and G. L. Zhao, Phys. Rev. B **61**, 16 582 (2000).

[26]G. L. Zhao, T. C. Leung, B. N. Harmon, M. Keil, M. Muller, and W. Weber, Phys. Rev. B **40**, 7999 (1989).

[27]G. L. Zhao and B. N. Harmon, Phys. Rev. B **45**, 2818 (1992).

[28]M. S. C. Mazzoni and H. Chacham, Appl. Phys. Lett. **76**, 1561 (2000).

[29]J. W. Mintmire, D. H. Robertson, and C. T. White, J. Phys. Chem. Solids **54**, 1835 (1993).

[30]T. W. Odom, J. L. Huang, P. Kim, and C. M. Lieber, J. Phys. Chem. B **104**, 2794 (2000).

[31]*CRC Handbook of Chemistry and Physics*, edited by R. C. Weast, D. R. Lied, M. J. Astle, and W. H. Beyer, (CRC Press, Boca Raton, FL, 1990), p. F-188.

[32]H. Matsumura and T. Ando, J. Phys. Soc. Jpn. **70**, 2657 (2001).

[33]M. Igami, T. Nakanishi, and T. Ando, J. Phys. Soc. Jpn. **70**, 481 (2001).

[34]J. N. Coleman, S. Curran, A. B. Dalton, A. P. Davey, B. McCarthy, W. Blau, and R. C. Barklie, Phys. Rev. B **58**, R7492 (1998).

[35]R. Tamura and M. Tsukada, Phys. Rev. B **58**, 8120 (1998).

[36]J. Callaway, *Quantum Theory of the Solid State* (Academic Press, New York, 1976), Chap. 4.

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THE BZW METHOD AND THE ELECTRONIC PROPERTIES OF ZINC SELENIDE (ZnSe)

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ABSTRACT—We present *ab-initio* and self-consistent calculations of the electronic structure and related properties of zinc selenide (ZnSe) in the zinc-blende structure. Our non-relativistic, zero-temperature calculations employed a local density functional potential, the linear combination of atomic orbitals (LCAO) formalism, and the Bagayoko, Zhao, and Williams (BZW) procedure. The BZW procedure avoids a recently identified basis set and variational effect inherent to the use of basis sets in variational calculations. There is excellent agreement between our findings and experimental results. Specifically, the calculated, direct, minimum band gap of ZnSe is 2.6 eV, while the practically measurable band gap range, as per the density of states, is from 2.6 eV to 3.1 eV. We discuss electronic energies, with emphasis on the low-energy conduction bands, the band gap, the density of states, and related properties.

Key words: zinc selenide, semiconductor, ZnSe, electronic structure, band gap.

INTRODUCTION

In the past several years, research on a wide-band-gap semiconductor, zinc selenide (ZnSe), has led to major advances which now make it viable for device applications (Morkoc et al. 1994). Because of outstanding properties and applications of ZnSe, a strong interest among scientists exists in its electronic and related properties. Until recently (G. L. Zhao et al. 1999, Bagayoko et al. 1998), LDA calculations for semiconductors often led to band gaps that are typically 30–50% smaller than the experimental values (Rubio et al. 1993, Vogel et al. 1997). The discrepancies between LDA and experimental results have been ascribed to limitations of the local-density approximation. The electronic structure of zinc-blende ZnSe was calculated by Wang and Klein (1981). They employed the linear combination of Gaussian orbitals (LCGO) method with a local density form of the exchange-correlation functional (LDA). Their calculated band gap for ZnSe was 1.83 eV. Wang and Klein's calculations underestimated the band gap of ZnSe by approximately 30% (Wang and Klein 1981). Huang and Ching (1993) performed a self-consistent calculation that employed the orthogonalized linear combination of atomic orbitals (OLCAO) method in a local density approximation (LDA). Their calculated band gap for zinc-blende ZnSe was 1.65 eV. The electronic band structures from both groups strongly agree. Oshikiri and Aryasetiawan (1999) utilized the linear muffin-tin-orbital (LMTO) method with the GW approximation, where G is the full Green's function, and W is the dynamically screened Coulomb interaction. Their GW approximation result for the band gap of ZnSe was 3.10 eV. Zakhorov et al. (1994) employed the *ab initio* pseudopotential method with the GW approximation. Their calculated band gap for ZnSe was 2.84 eV.

Experimental measurements of the electronic structure of zinc selenide have been reported by Zheng and Allen (1994) and Chow and Watkins (1999). Zheng and Allen (1994) performed photoionization spectrum studies. Chow and Watkins (1999) also conducted experimental electronic structure measurements for ZnSe with Electron Paramagnetic Resonance (EPR) and Optically Detected EPR (ODEPR) via photoluminescence. The experimental band gap obtained by Zheng et al. (1994) was 2.8 eV, and that found by Chow et al. (1999) was 2.82 eV. Additionally, reported results of the measured band gap of ZnSe, utilizing different experimental methods, are 2.8201 eV, 2.82 eV, and 2.70 eV at temperatures of 1.6 K, 10 K, and 295 K, respectively (Mandelung 1987).

Recently, Bagayoko and co-workers identified a basis set and variational effect inherently associated with the use of the linear combination of atomic orbital (LCAO) formalism in variational calculations of the Rayleigh-Ritz type (Zhao et al. 1999, Bagayoko et al. 1998, Williams 1998). Basically, the effect consists of a possible lowering of some unoccupied energy levels or bands for molecules, clusters, or solids on account of a mathematical fact (Gould 1957, Mikhlin 1971). This fact is stated in the theorem (Gould 1957) that describes the lowering or unchanged characteristic of any variational eigenvalue as the size of the basis set; i.e., the dimension of the matrices in the eigenvalue equation increases. The theorem simply states that a given variational eigenvalue, upon an increase of the size of the basis set, is never increased and that it remains either unchanged (i.e., if it is equal to the corresponding exact eigenvalue of the matrix) or it is lowered to approach the exact eigenvalue from above. Bagayoko and co-workers (Zhao et al. 1999, Bagayoko et al. 1998) identified the basis set and variational effect that consists of any lowering of unoccupied energy levels or bands beyond that which occurs before the "convergence" of the occupied levels with respect to the size of the basis set. They stated the possible, unphysical nature of such an "extra" lowering stems from the use of the wave functions *of occupied states only* in constructing the charge density, the potential, and the Hamiltonian from one iteration to the next.

Many different methods, which utilized different potentials, have been employed to obtain the electronic structure of ZnSe. Due to the above discrepancy between calculated and measured values of the band gap of ZnSe, further studies are clearly needed. We report our findings on the electronic structure and related properties of ZnSe. The purpose of this publication is to report the resolution of the above discrepancies between the theoretical calculations and the experimental measurements of the band gap of ZnSe. We successfully applied the Bagayoko, Zhao, and Williams (BZW) procedure (Zhao et al. 1999), briefly described below, to circumvent methodically the above basis set and variational effect while avoiding any possible "incomplete" nature of the basis set (Mikhlin 1971). In what follows, we first describe our method, with emphasis on the BZW procedure (Torrence 2000). We subsequently present the electronic energy bands, density of states, and related properties of zinc selenide. These results were obtained with the optimum basis set as determined by the BZW procedure.

METHODS

General Approach: LDA Potential and LCAO

Our calculations utilized an expanded version of the electronic structure calculation program package from the Ames Laboratory of the Department of Energy (DOE) in Iowa (Ching 1990, Feibelman et al. 1979, Harmon et al. 1982, Zhao et al. 1989, Zhao and Harmon 1992, Ching et al. 1987). Details of the computational method are available in several previous publications (Ching 1990, Feibelman et al. 1979, Harmon et al. 1982, Zhao et al. 1989, Zhao and Harmon 1992, Bagayoko et al. 1998). We employed the Ceperley-Alder type (Ceperley and Alder 1980) of local-density potentials as parameterized by Vosko, Wilk, and Nusair (1980). The above referenced publications describe the general features of our method, i.e., the LDA potential and the standard implementation of the LCAO. We discuss below our unique implementation of the LCAO method in a fashion that circumvents the basis set and variational effect noted above.

The BZW Procedure

In *ab-initio,* self-consistent calculations that employ the LCAO method, electronic eigenfunctions are expanded using basis sets derived from atomic calculations (Bagayoko et al. 1996, Dean et al. 1980). Charge densities and potentials are constructed using the wave functions of occupied states. The Hamiltonian matrix is generated and diagonalized. The key output quantities are energy levels or bands and related wave functions. The resulting output wave functions, for the occupied states only, are employed to generate a new charge density and the computations are repeated in an iterative process until self-consistency is reached. Various measures are utilized to define self-consistency; i.e., when basic quantities, including charge densities, potentials, eigenenergies, etc., are unchanged from one iteration to the next.

The BZW procedure suggests a minimum of three self-consistent calculations that utilize basis sets of different sizes. It generally begins with the minimum basis set; i.e., the basis set needed to account for all the electrons of the atomic or ionic species that are present in a molecule, a cluster, or a solid. In the case of ZnSe, we chose these species to be Zn^{1+} and Se^{1-}. Completely self-consistent calculations are carried out. For the second calculation, the minimal basis set is augmented with one or more atomic orbitals that belong to the next and lowest-lying energy levels in the atomic or ionic species. The self-consistent occupied energies from calculations I and II are compared, graphically and numerically. They are generally different. Subsequent self-consistent calculations are carried out with a basis set including that for the previous calculation plus one or more orbitals that belong to the next and lowest-lying energy levels in the atomic or ionic species. Again, the output energies, for occupied states, are compared. This process continues until the comparison of the occupied energy levels for calculation N and calculation (N+1) leads to no qualitative (shape and branching) and no quantitative (numerical values) difference. When the

TABLE 1. Basis Set Composition. Orbitals added to the minimal basis set (basis set I), are in bold.

Basis set #	Zinc core	Selenium core	Zinc valence	Selenium valence
I	1s, 2s, 2p	1s, 2s, 2p	3s, 4s, 3p, 3d	3s, 4s, 3p, 4p, 3d
II	1s, 2s, 2p	1s, 2s, 2p	3s, 4s, 3p, **4p**, 3d	3s, 4s, 3p, 4p, 3d
III	1s, 2s, 2p	1s, 2s, 2p	3s, 4s, 3p, **4p**, 3d	3s, 4s, 3p, 4p, 3d, **4d**
IV	1s, 2s, 2p	1s, 2s, 2p	3s, 4s, 3p, **4p**, 3d, **4d**	3s, 4s, 3p, 4p, 3d, **4d**
V	1s, 2s, 2p	1s, 2s, 2p	3s, 4s, 3p, 4p, 3d, 4d	3s, 4s, **5s**, 3p, 4p, 3d, 4d

occupied energies from calculation N and those from calculation (N+1) agree within the computational error, then the optimum basis set is that of calculation N.

Computational Details

The zinc-blende ZnSe is a member of the II-VI family, and the T_d^2 space group. Our calculations utilized a zero temperature lattice constant of a=10.676957 (5.65 Å). The atomic wavefunctions of the ionic states of Zn^{1+} and Se^{1-} were obtained from self-consistent *ab-initio* atomic calculations. The radial parts of the atomic wave functions were expanded in terms of Gaussian functions. A set of even-tempered Gaussian exponentials was employed with a minimum of 1.500×10^{-1} and a maximum of 1.770×10^{5}. We used 18 Gaussian functions for the *s* and *p* states and 15 for the *d* states for Zn. We utilized 19 Gaussian functions for the *s* and *p* states and 17 for the *d* states for Se. A mesh of 28 *k* points, with proper weights in the irreducible Brillouin zone, was employed in the self-consistent iterations. The high symmetry points utilized in the body-centered cubic (bcc) Brillouin zone are L, Γ, X, and K. The positions for the high symmetry points are $L=\pi/a(1/2,1/2,1/2)$, $\Gamma=(0,0,0)$, $X=2\pi/a(1,0,0)$ and $K=2\pi/a(3/4,3/4,0)$. The computational error for the valence charge was about 0.00247377 for 44 electrons. The self-consistent potentials converged to a difference around 10^{-5} after about 60 iterations. The total number of iterations varied with the input potentials.

RESULTS

We have calculated the electronic structure and related properties of zinc-blende ZnSe by first calculating the electronic energy bands, secondly, the total density of states, and finally, the effective mass (m^*_n) of n-type carriers. We performed five calculations in order to determine the optimal basis set as per the BZW procedure. Table 1 illustrates the basis set composition for all five self-consistent calculations. The calculation of the electronic energy bands first consisted of carrying out completely self-consistent calculations for ZnSe using a minimal LCAO basis set along the high symmetry points, L Γ X K Γ, of the Brillouin zone. The initial charge density for ZnSe was calculated using the atomic orbitals of Zn (1s2s3s4s, 2p3p, 3d) and Se (1s2s3s4s, 2p3p4p, 3d). We then repeated the self-consistent

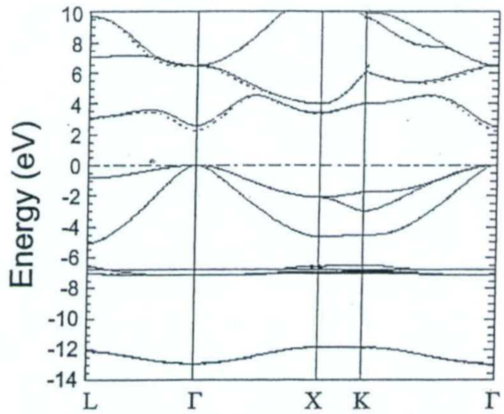

FIGURE 1. Calculated, self-consistent, electronic band structure of ZnSe in the zinc-blende structure, using the BZW method. The solid and dashed lines, respectively, show our results from calculation IV and V. The occupied energies from Calculations IV and V are equal, for any k-point.

calculation using the above basis set as augmented by the orbitals describing the next lowest-lying energy levels of Zinc. Hence, Zn ($4p^0$) orbitals were added to the minimal basis set, where the superscript index of zero indicates that these states are unoccupied in the free atoms (ions). We then plotted the energy bands from these two distinct calculations, i.e., calculation I and calculation II, and compared them numerically and graphically. Differences were obvious. We then performed calculation III and compared its results to those of calculation II. Up to five self-consistent calculations were performed and the results of each calculation were compared to those of the previous one as explained above. Figure 1 shows a comparison plot of results from basis set IV (solid line) and from basis set V (dashed line). The convergence of *occupied energy levels* with respect to the size of the basis set is apparent in this graph. According to the BZW procedure, given the total convergence of occupied energy levels, we selected basis set IV as the optimal basis set. The results discussed below for the energy bands and related properties were obtained with basis set IV.

Figure 1 shows our calculated, theoretical, "minimum" band gap to be about 2.6 eV; i.e., the difference between the energies for the minimum conduction band of basis set IV (solid line) and the topmost valence band. Figure 1 also shows that ZnSe is a direct gap semiconductor with the smallest energy gap at the center of the Brillouin zone (Γ). The valence band maximum has Se 4p character, and the Zn 3d bands fall in the middle of the sp valence band manifold, between −6 and −8 eV. Table 2 shows some calculated and experimental band gaps obtained by various groups for the zinc-blende structure of ZnSe. This table clearly shows that, with applicable uncertainties, our calculations are in good agreement with the experimental measurements of Zheng and Allen (1994) and Chow and Watkins (1999).

Figure 2 shows the total density of states (DOS) for ZnSe, obtained from calculation IV or with basis set IV of the BZW method. Our total DOS curve in Figure 2, particularly the insert, indicates that the calculated,

TABLE 2. Comparison of theoretical (calculated) and experimental band gaps of zinc selenide (ZnSe) in the zinc-blende structure.

Reference	Band gap E_g (eV)	Method	Potential
		Theoretical results	
Wang and Klein 1981	1.83	LCGO	LDA
Huang and Ching 1993	1.65	OLCAO	LDA
Dröge et al. 2000	1.96	*ab-initio*	LDA
Markowski et al. 1994	1.22 (with spin-orbit coupling) 1.13 (without spin-orbit coupling)	LMTO	LDA
This work	*2.6–3.1	LCAO	LDA
Oshikiri and Aryasetiawan 1999	3.10	LMTO	GW
Zakhorov et al. 1994	2.84	*ab initio* pseudopotential	GW
		Experimental results	
Zheng and Allen 1994	2.8	Photoionization spectrum	N/A
Chow and Watkins 1999	2.82	EPR and ODEPR	N/A
Madelung 1987	2.8201 (1.6K) 2.82 (10K) 2.70 (295K)	From exciton data Wavelength modulated reflectivity (See Madelung 1987)	N/A
Stutius and Ponce 1985	2.6 (room temperature)	Van der Pauw technique and high resolution TEM	N/A
Chu et al. 1992	2.6 (room temperature)	Metalorganic chemical vapor depostion	N/A
Shahzad et al. 1989	2.82 (6K)	Photoluminescence (PL)	N/A
Yoshino et al. 2001	2.80 (77K) 2.70 (300K)	Piezoelectric Photothermal (PPT) spectroscopy	N/A

* The minimum theoretical band gap is 2.6 eV. The practically measurable band gap range is 2.6–3.1 eV, as per the density of states (DOS) curve.

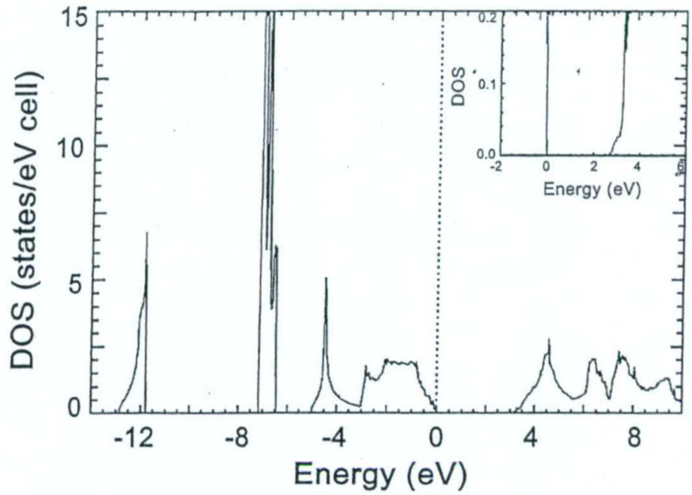

FIGURE 2. The calculated Density of States (DOS) of Zinc Selenide (ZnSe) in the zinc-blende structure obtained with the BZW optimal basis set (i.e., Calculation IV).

practically measurable band gap (Zhao et al. 1999) for ZnSe is in the range of 2.6–3.1 eV, in excellent agreement with the experimental measurements. The sharp peak between −7.5 eV and −6.5 eV belongs to the Zn 3d bands. The s-like, lowest bands of the valence states lie in a narrow range between −12.5 eV and −12 eV. As explained elsewhere (Bagayoko et al. 1998), the very small values of the density of states from 2.6 eV to 3.1 eV strongly suggest that measurements or related analysis that are not very sensitive may not detect the smallest gap. The density of state is about 0.03, as per the insert in Figure 2, for energies around 3.0 eV. The density of states sharply rises above 0.2, a value ten times larger than the one for energies below 3.0 eV. This observation leads to the notion of the practically measurable band gap, between 2.6 eV and 3.1 eV, for ZnSe. The experimental band gap of 2.82 eV (Chow and Watkins 1999), for low temperatures, falls in the range of this practical band gap.

Our calculated effective mass for n-type carriers, m^*_n, near the Γ point is $0.16m_o$, where m_o is the free-electron mass. This result is in good agreement with the experimental value of $0.16m_o$ (Dean et al. 1980). The calculated effective mass of n-type carriers, away from the Γ point, is between $0.16m_o$ to $0.18m_o$.

ACKNOWLEDGMENTS

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Literature Cited

Bagayoko, D., G.L. Zhao, J.D. Fan, and J.T. Wang. 1998. *Ab initio* calculations of the electronic structure and optical properties of ferroelectric tetragonal $BaTiO_3$. J. Phys. Cond. Matt. 10:5645–5655.

Bagayoko, D., P.M. Lam, N. Brener, and J. Callaway. 1996. 3*d* transition-metal impurities in aluminum. Phys. Rev. B. 54:12184–12193.

Ceperley, D.M. and B.J. Alder. 1980. Ground state of the electron gas by a stochastic method. Phys. Rev. Lett. 45:566–569.

Ching, W.Y. 1990. Theoretical studies of the electronic properties of ceramic materials. J. Am. Ceram. Soc. 73:3135–3160.

Ching, W.Y., Y. Xu, G.L. Zhao, K.W. Wong, and F. Zandiehnadem. 1987. Electronic structure and excitonic-enhanced superconducting mechanism in $YBa_2Cu_3O_{7\text{-}delta}$. Phys. Rev. Lett. 59:1333–1336.

Chow, K.H. and G.D. Watkins. 1999. Electronic structure and migrational properities of interstitial zinc in ZnSe. Phys. Rev. B. 60:8628–8639.

Chu, T.L., S.S. Chu, G. Chen, J. Britt, C. Ferekides, and C.Q. Wu. 1992. Zinc selenide films and heterojunctions. J. Appl. Phys. 71:3865–3869.

Dean, P.J., D.C. Herbert, and A.M. Lakee. 1980. Proc. 15th Int. Conf. Physics of Semiconductors, Kyoto, J. Phys. Soc. Jpn. 49 Suppl. A, 185.

Dröge, H., M. Nagelstraßer, J. Nürnberger, W. Faschinger, A. Fleszar, and H.-P. Steinrück. 2000. The electronic band structure of ZnSe (100). Surface Science 454–456:477–482.

Feibelman, P.J., J.A. Appelbaum, and D.R. Hamann. 1979. Electronic structure of a Ti(0001) film. Phys. Rev. B. 20:1433–1443.

Gould, S.H. 1957. Variational Methods for Eigenvalue Problems. University of Toronto Press, Toronto. 275 pp.

Harmon, B.N., W. Weber, and D.R. Hamann. 1982. Total-energy calculations for Si with a first-principles linear-combination-of-atomic-orbitals method. Phys. Rev. B. 25:1109–1115.

Huang, M. and W.Y. Ching. 1993. Calculation of optical excitations in cubic semiconductors. I. Electronic structure and linear response. Phys. Rev. B. 47:9449–9463.

Madelung, O., W. von dre Osten, and U. Rössler. 1987. Numerical data and functional relationships in science and technology. Landolt-Börnstein, New Series, Group III 22: 176–185.

Markowski, R., M. Piacentini, D. Debowska, M. Zimnal-Starnawska, F. Lama, N. Zema, and A. Kisiel. 1994. Electronic structure of zincblende ZnSe: theory and experiment. J. Phys. Cond. Matt. 6:3207–3219.

Mikhlin, S.G. 1971. The Numerical Performance of Variational Methods. Wolters–Noordhoff, Groningen. 373 pp.

Morkoc, H., S. Strite, G.B. Gao, M.E. Lin, B. Sverdlov, and M. Burns. 1994. Large-band-gap SiC, III-V nitride, and II-VI ZnSe-based semiconductor device technologies. J. Appl. Phys. 76:1363–1398.

Oshikiri, M. and F. Aryasetiawan. 1999. Band gaps and quasiparticle energy calculations on ZnO, ZnS, and ZnSe in the zinc-blende structure by the GW approximation. Phys. Rev. B. 60:10754–10757.

Rubio, A., J.L. Corkill, M.L. Cohen, E.L. Shirley, and S.G. Louie. 1993. Quasiparticle band structure of AlN and GaN. Phys. Rev. B. 48:11810–11816.

Shahzad, K., D. Olego, and D. Cammack. 1989. Optical transitions in ultra-high-purity zinc selenide. Phys. Rev. B Rapid Comm. 39:13016–13019.

Stutius, W. and F.A. Ponce. 1985. Crystal orientation dependence of the electrical transport and lattice structure of zinc selenide films grown by metalorganic chemical vapor deposition. J. Appl. Phys. 58:1548–1553.

TORRENCE, L. 2000. The bzw method and the electronic properties of Zinc Selenide (ZnSe). M.S. Thesis. Southern University and A&M College, Baton Rouge, Louisiana. 43 pp.

VOGEL, D., P. KRÜER, AND J. POLLMANN. 1997. Structural and electronic properties of group-III nitrides. Phys. Rev. B. 55:12836–12839.

VOSKO, S.H., L. WILK, AND M. NUSAIR. 1980. Accurate spin-dependent electron liquid correlation energies for local spin density calculations: a critical analysis. Can. J. Phys. 58:1200–1211.

WANG, C.S. AND B.M. KLEIN. 1981. First-principles structure of Si, Ge, GaP, GaAs, ZnS, and ZnSe. I. Self-consistent energy bands, charge densities, and effective mass. Phys. Rev. B. 24:3393–3416.

WILLIAMS, T.D. 1998. Electronic structure and optical properties of ruthenium dioxide. M.S. Thesis. Southern University and A&M College, Baton Rouge, Louisiana.

YOSHINO, K., H. MIKAMI, K. IMAI, M. YONETA, AND T. IKARI. 2001. Optical characterization of native defects in ZnSe substrate. Physica B. 302:299–306.

ZAKHAROV, O., A. RUBIO, X. BLASE, M.L. COHEN, AND S.G. LOUIE. 1994. Quasiparticle band structures of six II-IV compounds: ZnS, ZnSe, ZnTe, CdS, CdSe, and CdTe. Phys. Rev. B. 50:10780–10787.

ZHAO, G.L. AND B.N. HARMON. 1992. Phono anomalies in *beta*-phase Ni_xAl_{1-x} alloys. Phys. Rev. B. 45:2818–2824.

ZHAO G.L., D. BAGAYOKO, AND T.D. WILLIAMS. 1999. Local-density-approximation prediction of electronic properties of GaN, Si, C, and RuO_2. Phys. Rev. B. 60:1563–1572.

ZHAO, G.L., T.C. LEUNG, B.N. HARMON, M. KEIL, M. MULLER, AND W. WEBER. 1989. Electronic origin of the intermediate phase of NiTi. Phys. Rev. B. 40:7999–8001.

ZHENG, J.Z. AND J.W. ALLEN. 1994. Conduction-band intervalley spacing in zinc selenide obtained from the photoionization spectrum of a deep level. Phys. Rev. B. 49:7770–7773.

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DENSITY OF STATES, CHARGE TRANSFER, AND OPTICAL PROPERTIES OF MAGNESIUM DIBORIDE

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We performed *ab-initio*, local density functional calculations of the electronic structure, charge transfer, and optical properties of MgB_2, using the LCAO formalism. The Fermi level of MgB_2 cuts through relatively narrow electron bands which have a dominant contribution from B(2*p*) states. There is a substantial charge transfer from magnesium to boron atoms. We found the ionic formula for this material to be $Mg^{1.68+}B_2^{0.84-}$. A clearly metallic distribution of the electronic charge density in the plane of boron atoms is interwoven with a visibly covalent one in the direction perpendicular to this plane. The calculated optical conductivities from the direct inter-band transitions exhibit a strong anisotropy between $\sigma_{xx}(\omega)$ or $\sigma_{yy}(\omega)$ and $\sigma_{zz}(\omega)$. Due to our application of the BZW procedure, major peaks in the density of states above the Fermi level are at markedly higher energies (1–1.5 eV) than the results of previously reported ones. A similar pattern is followed by our findings for optical conductivities.

Keywords: MgB_2; electronic structure; charge transfer; optical properties.

1. Introduction

The recent discovery of superconductivity in magnesium diboride (MgB_2)[1] with $T_c = 39$ K has attracted much attention around the world.[2–6] Although hexagonal MgB_2 was identified in the 1950's, its physical properties are not well studied. In 1979, Armstrong and Perkins reported a calculation of the electronic band structure of MgB_2 using an empirical method.[7] Their calculated electron bands of MgB_2 are substantially different from recent *ab-initio*, density functional calculations that are presented in several electronic-preprints[8–10] and this work. In this report, we present the calculated electronic band structure, the total density of states and the partial contribution from the *s* and *p* states of Mg and B, the calculated charge transfer, and the optical properties of MgB_2.

In the next section, we summarize the computational details. The calculated results are presented in Sec. 3. They are followed by a short conclusion in Sec. 4.

2. Method

MgB_2 crystallizes in the hexagonal AlB_2-type structure of space group D^1_{6h}. The experimentally measured lattice constants a and c are 3.084 Å and 3.522 Å, respectively.[1,11] The hexagonal MgB_2 has a relatively simple structure. There are three atoms per unit cell. The atomic positions are: 1 magnesium atom in 1(a) (0, 0, 0), and 2 boron atoms in 2(b) (1/3, 2/3, 1/2) and (2/3, 1/3, 1/2), of the space group D^1_{6h}. There are alternating layers of Mg atoms and graphite like honeycomb layers of B atoms. The B-B bond length is 1.78 Å, whereas the shortest Mg-B distance is 2.50 Å.

Our *ab-initio* calculations utilized the linear combination of atomic orbital (LCAO) method. The self-consistent LCAO calculations included all electrons and full potentials, without shape approximations. Details of the general computational method are available in previous publications.[12–16] We employed the Ceperley–Alder type[17] of the local density functional potential as parameterized by Vosko, Wilk, and Nusair[18] to describe the many body exchange-correlation interactions of the electron system.

We began the calculation with self-consistent, *ab-initio* computations for the neutral Mg and B atoms. The radial parts of the atomic wave functions were expanded in terms of Gaussian functions. A set of even tempered Gaussian exponents was employed with a minimum of 0.12 and a maximum of 0.15×10^6, in atomic unit.

We then performed self-consistent calculations for the electronic structure of MgB_2 and obtained an estimate of the charge transfer. These preliminary results suggested that Mg and B in MgB_2 will be close to Mg^{2+} and B^{1-}, respectively, as opposed to neutral species. We subsequently performed self-consistent calculations for free Mg^{2+} and B^{1-} ions to obtain the atomic functions that served as the input for the solid state calculations.

Our solid state calculations employed the Bagayoko, Zhao, and Williams (BZW) method that has been extensively described in our previously publications.[14–16] Hence, we performed several self-consistent calculations with increasing sizes of the basis set, starting with the minimal basis set. This minimal basis set is just large enough to account for all the electrons in the atomic or ionic species in the system (i.e. Mg^{2+}, B^{1-}). The final results reported here are from the calculation with the optimal basis set, i.e. the smallest basis set for which the occupied energy bands converge vis-a-vis the size of the basis set.[14–16] Specifically, calculations with basis sets larger than the optimal basis lead to the same occupied bands (in shape, branching, and numerical values) as those obtained with the optimal basis set.

In the self-consistent calculations of the electronic structure of MgB_2, we took Mg($1s$) and B($1s$) as the core states. Other states such as Mg($2s3s$ $2p3p$) and B($2s3s$ $2p$) are included as valence states in the self-consistent calculations. Here, Mg($3p^0$) and B($3s^0$) are empty shells in the free atoms (or ions) and are used to augment the basis set to account for charge redistributions in the solid environment. We used 80

k-points with proper weights in the irreducible Brillouin zone in the self-consistent calculations. The computational error for the valence charge was about 0.003 for 16 electrons. The computation for the exchange-correlation potentials was done in real space using a mesh of points around each atom. The numbers of mesh points per atomic site varied from 7028 to 7088, depending on the local structure of the atom. The self-consistent potentials converged to a difference around 10^{-5}.

From the resulting electronic energy levels and wavefunctions, we calculated the optical excitations of direct interband transitions and their contributions to the optical conductivity $\sigma_{\mu\mu}(\omega)$, using the Kubo–Greenwood formula.[19]

$$\sigma_{\mu\mu}(\omega) = \frac{2\pi e^2}{m^2\omega\Omega}\sum_{\mathbf{k}}\sum_{nl} |\langle\Psi_{\mathbf{k}n}(\mathbf{r})|P_\mu|\Psi_{\mathbf{k}l}(\mathbf{r})\rangle|^2 f_{\mathbf{k}l}[1 - f_{\mathbf{k}n}]\delta(\epsilon_{\mathbf{k}n} - \epsilon_{\mathbf{k}l} - \hbar\omega) \quad (1)$$

where $\hbar\omega$ is the photon energy; Ω is the volume of the unit cell; $P_\mu = -i\hbar(\partial/\partial x_\mu)$; $\epsilon_{\mathbf{k}n}$ is the eigen-energy associated with the eigen-state $|\Psi_{\mathbf{k}n}\rangle$ at $\mathbf{k}$-point for band index n.

3. Results

We have calculated the electronic properties of MgB_2 using the newly introduced procedure.[14–16] Succinctly stated, the implementation of the new calculation procedure first consisted of carrying out completely self-consistent calculations using a minimal LCAO basis set. Namely, the initial charge density for MgB_2 was calculated using the atomic orbitals of Mg($1s2s3s$ $2p$) and B($1s2s$ $2p$).

We then repeated the self-consistent calculation using the above basis set as augmented by the orbitals describing the lowest excited state of Mg. Hence, Mg($3p^0$) orbitals were added to the basis set. We then plotted the energy bands obtained from these two distinct self-consistent calculations. In Fig. 1, the solid and dashed lines represent the calculated results from the first and second calculations, respectively. The Fermi level is set at 0.0 eV. The notations of the high symmetry points in Fig. 1 follows Koster's discussion of space groups.[20] Figure 1 shows that the occupied bands from the two calculations differ slightly near the H and K points.

The next step was to repeat our procedure, for a third time, with a new basis set that includes B($3s^0$) orbital. The results of this third calculation (dashed lines) and of the second calculation (solid lines) are shown in Fig. 2. The calculated occupied bands as well as the unoccupied bands in Fig. 2 converge to a difference at the order of 1 mRy, that is in the range of computational errors that are due to other factors, including rounding errors and possible limitations of LDA.

Hence, as noted above, the larger basis set, for the third self-consistent calculation, is preferred to that of the minimal basis set calculation. This preference is based on physical considerations, i.e. actual, physical interactions are responsible for the difference between the two sets of bands. Completeness requirements, partly to describe the redistribution of the electronic cloud in the solid environment, dictate this preference.

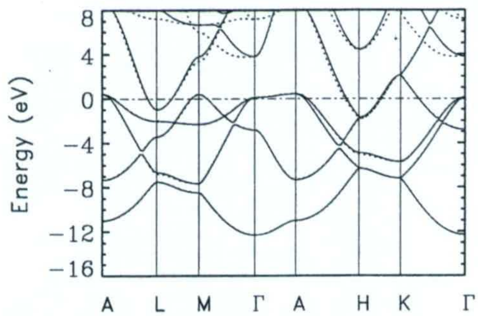

Fig. 1. The comparison of the results of Calculation I and II. The solid lines represent the bands of MgB_2 from the minimum basis set calculation (Calculation I); the dashed lines show the bands from calculation II.

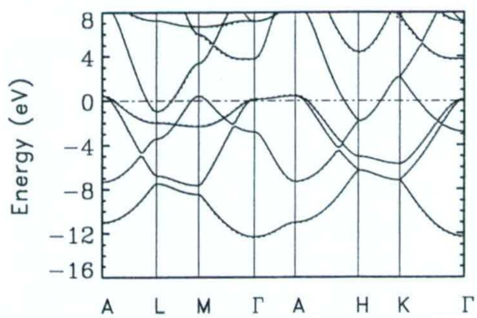

Fig. 2. The comparison of the results of Calculation II and III. The solid lines represent the results from Calculation II; the dashed lines show the electron energy bands of MgB_2 from Calculation III.

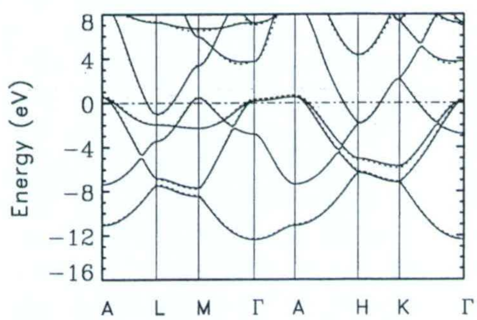

Fig. 3. The comparison of the results of Calculation III and IV. The solid lines represent the electron energy bands of MgB_2 from Calculation III; the dashed lines show the bands from Calculation IV.

Furthermore, we added $B(3p^0)$ orbitals to the basis set of the third calculation. The results of this fourth calculation (dashed lines) and of the third calculation (solid lines) are shown in Fig. 3. Again, the calculated occupied bands and the unoccupied bands in Fig. 3 are fully converged.

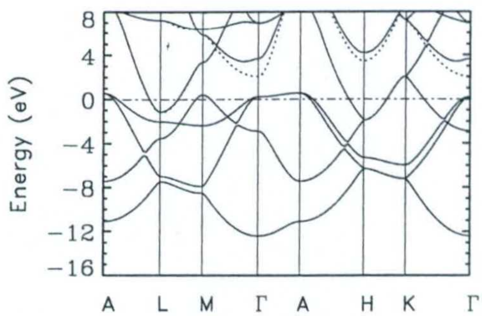

Fig. 4. The comparison of the results of Calculation IV and V. The solid lines represent the results from Calculation IV; the dashed lines show the bands from Calculation V.

Table 1. The atomic orbitals used in our self-consistent calculations of the electronic structure of MgB_2 applying the LCAO method.

	Basis Set
Calculation I	Mg($1s2s3s$ $2p$), B($1s2s$ $2p$)
Calculation II	Basis Set I + Mg($3p^0$)
Calculation III	Basis Set II + B($3s^0$)
Calculation IV	Basis Set III + B($3p^0$)
Calculation V	Basis Set IV + Mg($4s^0$)
Calculation VI	Basis Set V + Mg($3d^0$)

However, without the method discussed by Bagayoko, Zhao, and Williams,[14–16] the test calculations of including more orbitals will continue indefinitely. We presented in Fig. 4 the results of the fourth calculation (solid lines) and the fifth calculation (dashed lines) for which Mg($4s^0$) orbital is added. In contrast to the unchanged nature of the occupied states, some of the low unoccupied states near the Γ and H symmetry points are shifted downward by approximately 1 to 1.6 eV. In light of the discussions presented in our previous publications, the drastic changes in the unoccupied states, in going from calculation IV to V, are believed to be the consequences of the Rayleigh theorem as discused in related mathematical books,[21,22] since the charge density, potential, and Hamiltonian do not change. While no other graphs are shown here, we continued to add orbitals of higher and higher excited states to the basis set for further calculations. As expected, these calculations did not lead to changes in the occupied states, charge density, and Hamiltonian. They led, expectedly, to drastic changes in unoccupied bands. Consequently, these changes led to a difference in the calculated optical properties, as discussed later. We summarize the atomic orbitals used in Calculation I to VI in Table 1.

Therefore, the electronic band structure of MgB_2, obtained with the optimum basis set of calculation III, is shown as the solid lines of Fig. 3. Our calculated band structure agrees well with other recent *ab-initio* calculations,[8–10] but is substantially different from the results reported by Armstrong and Perkins.[7] Our calculated band width for the occupied valence states is 12.3 eV. Armstrong and Perkins reported the band width of the occupied states to be about 28 eV.[7] The electronic energy bands of MgB_2, the solid lines of Fig. 3, show that the Fermi level of MgB_2 cuts through the relatively narrow electron bands which have a dominant contribution of B(2p) states. This shows that boron layers are in a metallic state, with the dominant contribution to the electron–phonon coupling that is reported to be responsible for the superconductivity of MgB_2.[4]

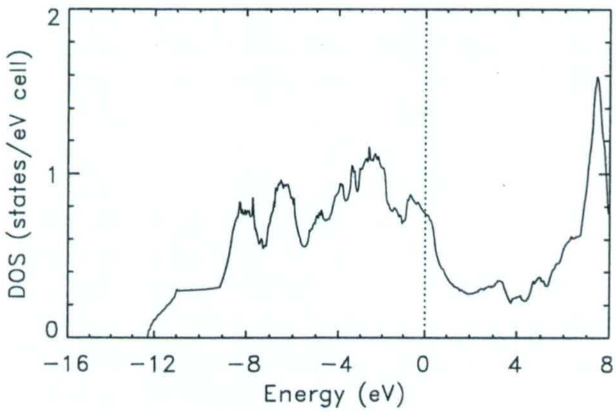

Fig. 5. The calculated density of states of MgB_2.

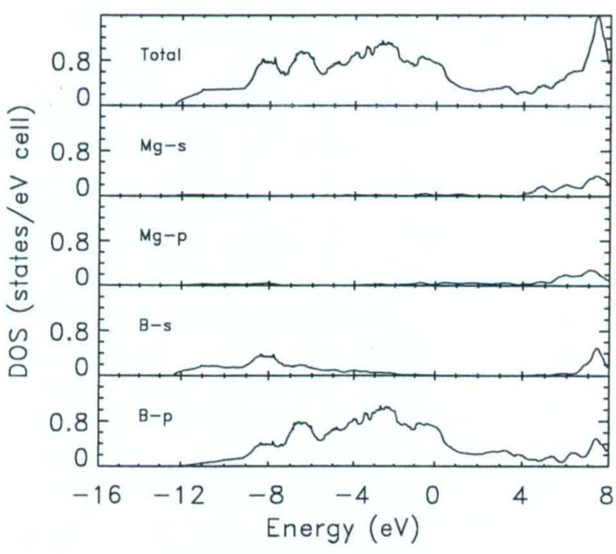

Fig. 6. The calculated partial density of states of MgB_2.

The metallic behavior of boron layers can also be seen from the calculated total and partial density of states (DOS) in Figs. 5 and 6. It shows that the occupied valence electron states below the Fermi level (at 0 eV) are mainly attributed to B(2s) and (2p) states. Mg(3s) and (3p) states only contribute about 4% to the total occupied states as shown in Fig. 6, whereas the 2s and 2p states of two B atoms in a unit cell give a contribution up to about 96%. As we discussed in previous publications,[23,24] the variation of the density of states around the Fermi level, within the range of phonon energy, can have a noticeable effect on the total electron–phonon coupling matrix elements. Figure 6 shows a noticeable variation of the density of states around E_F. Such effect may lead to an exponent of the boron isotopic effect on T_c, α_B, that is different from 1/2. The experimentally observed boron isotope exponent α_B is about 0.26.[4]

While our density of states are the same as the calculated ones recently reported,[8] for the occupied states, they are markedly different for the unoccupied states. This difference stems from our application of the BZW method as explained elsewhere.[14–16] In particular, the stiff increase of the density of unoccupied states around 5 eV, as reported by Kortus *et al.*,[8] does not occur in our results until one reaches 6.5 eV. Naturally, this difference will carry over to the description of the contributions of inter-band transitions to the optical conductivity. This result partly modifies our previous suggestion that the BZW[15] procedure may not be needed for materials that are known to be metallic. While this observation holds for occupied states and the unoccupied ones very close to the Fermi level, it does not for relatively high conduction bands. Consequently, the method is still needed for metals as long as excited state energies and related quantities (DOS, optical conductivity, etc) are of interest.

Using the calculated electron wave functions and the LCAO method, we calculated the effective charges and charge transfer in MgB_2. The calculated charge transfers indicate that each Mg atom loses about 1.68 electrons that are gained by two B atoms. The ionic formula for this material can be written as $Mg^{1.68+}B_2^{0.84-}$. The computational error for the charge transfer was estimated at about ± 0.2 electrons.

Figures 7 and 8 show the contour plots of the electron distribution in real space on a boron plane and on a (010) plane that contains Mg and B atoms. The unit of the labeled charge density values is 10^{-2} electrons/a_0^3, where $a_0 = 0.529177$ Å. The high charge density region around the nuclear sites has been cut off at a value of 0.15 electrons/a_0^3, leaving hollow spheres to represent the atomic cores in the figures. The distribution of electrons is strikingly anisotropic. The usual contour map in Fig. 7, in the boron plane, indicates a delocalization of electrons along the ring of the honeycomb. This map denotes the metallic character of the boron plane. In contrast, clearly covalent bonds, between pairs of boron species, characterize the charge distribution in the c direction that is perpendicular to the boron plane (Fig. 8).

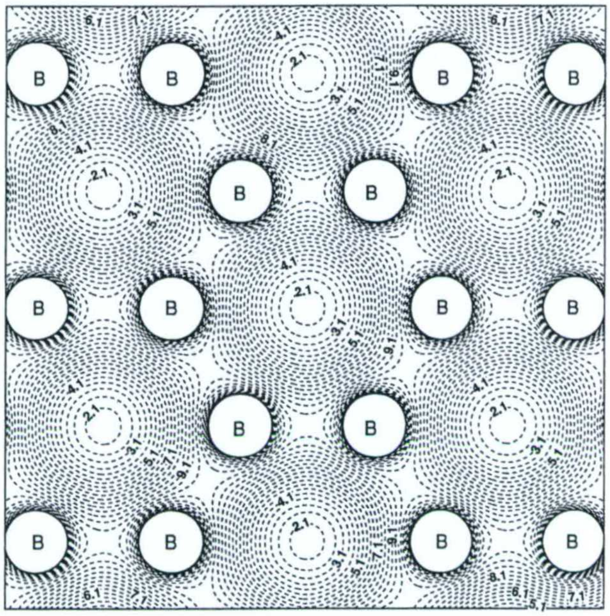

Fig. 7. The contour plots of the calculated electron distribution in real space on a boron plane.

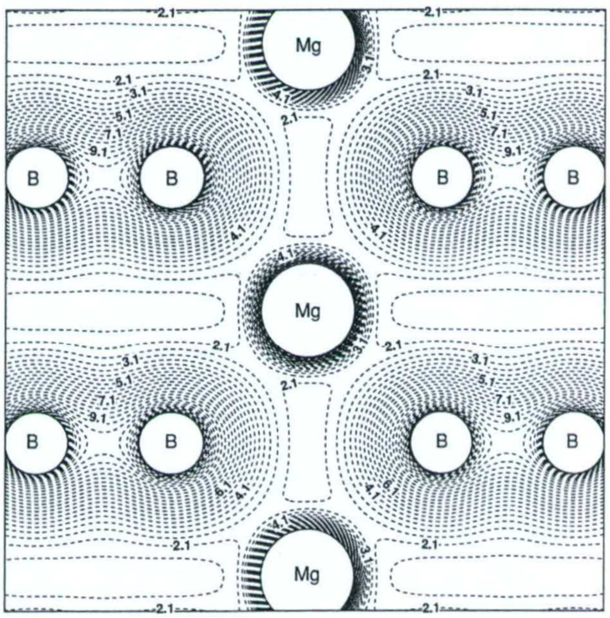

Fig. 8. The contour plots of the electron distribution in realspace on a (010) plane containing Mg and B atoms.

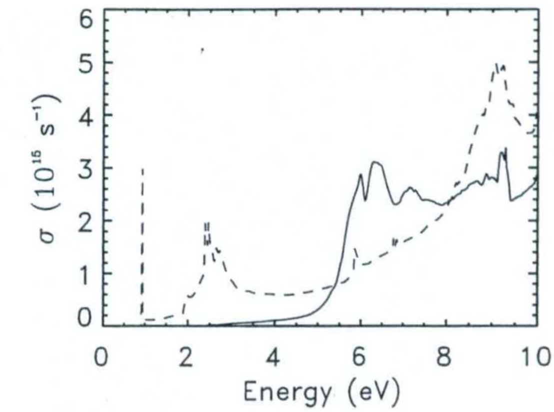

Fig. 9. The calculated optical conductivity of MgB_2. The solid line presents $\sigma_{zz}(\omega)$; the dashed line presents $(\sigma_{xx}(\omega) + \sigma_{yy}(\omega))/2$.

We present the calculated optical conductivity from the direct band transitions for MgB_2 in Fig. 9. In the calculation of the optical conductivity using Eq. (1), we employed a much denser mesh of 929 k-points in the irreducible Brillouin. The intra-band transitions, which account for the optical conductivity of low excitation energies of less than about 1 eV, can be described by the Drude term. They are not included in this calculation. The solid line in Fig. 9 shows the optical conductivity $\sigma_{\|}(\omega) = \sigma_{zz}(\omega)$, for light polarization along the c-direction. The dashed line represents the optical conductivity $\sigma_{\perp}(\omega) = (\sigma_{xx}(\omega) + \sigma_{yy}(\omega))/2$, for polarization perpendicular to the c-direction. The optical conductivities in Fig. 9 show a strong anisotropy. $\sigma_{\perp}(\omega)$ is substantially stronger than $\sigma_{\|}(\omega)$ in the excitation energy range of 0.9 eV to 3 eV. This anisotropy of the optical conductivity is attributed to the characteristic of the occupied electronic states near the Fermi level, with a strong contribution from B (p_x, p_y) components of the σ-bands. The sharp structure of $\sigma_{\perp}(\omega)$ near 0.93 eV is attributed to large matrix elements of optical transitions of energy bands around E_F for a very narrow region in k-space near the half way from the symmetry points A to L. This sharp structure can be smeared in experimental measurements, due to thermal effect and other defects in the sample, as we observed when using a broadening method to calculate it. Although, the strong anisotropy of the optical conductivity and other futures are similar to the calculated results of $\epsilon_2(\omega)$ reported by Ravindran, *et al.*,[25] the peak positions in their calculated $\epsilon_2(\omega)$ are shifted down substantially in comparison with our calculated $\sigma_{\perp}(\omega)$. This difference may partly due to the lowing of their calculated conduction bands as we discussed earlier.

4. Conclusion

We have calculated the electronic structure and the optical properties of MgB_2. We performed the *ab-initio*, local density functional calculations in the LCAO formalism. The electronic states near the Fermi level are dominated by the B (p_x, p_y) states of the σ-bands. The boron layers are in a metallic state while covalence characterizes the distribution of electrons (around boron) in the c-direction. They give the dominant contribution to the electron–phonon coupling. There is a substantial charge transfer from magnesium to boron atoms. The ionic formula for this material may be written as $Mg^{1.68+}B_2^{0.84-}$. There is a marked difference between $\sigma_{xx}(\omega)$ or $\sigma_{yy}(\omega)$ and $\sigma_{zz}(\omega)$. Our results for the charge transfer and the locations of peaks in the density of states and optical conductivities await experimental findings for comparison.

Acknowledgment

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References

1. J. Nagamatsu, N. Nakagaw, T. Muranaka, Y. Zenitani and J. Akimitsu, *Nature* **410**, 63 (2001).
2. D. C. Larbalestler, L. D. Cooley, M. O. Rikel, A. A. Polyanskii, J. Jiang, S. Patnalk, X. Y. Xai, D. M. Feldmann, A. Gurevich, A. A. Squitlerrl, M. T. Naus, C. B. Eom, E. E. Hellstrom, R. J. Cava, K. A. Regan, N. Rogado, M. A. Hayward, T. He, J. S. Slusky, P. Khallfah, K. Inumaru and H. Hass, *Nature*, **410**, 186 (2001).
3. J. S. Slusky, N. Rogado, K. A. Regan, M. A. Hayward, P. Khallfah, I. He, K. Inumaru, S. M. Loureiro, M. K. Hass, H. W. Znadgergen and R. J. Cava, *Nature* **410**, 343 (2001).
4. S. L. Bud'ko, G. Lapertot, C. Petrovic, C. E. Cunningham, N. Anderson and P. C. Canfield, *Phys. Rev. Lett.* **86**, 1877 (2001).
5. D. K. Finnemore, J. E. Ostenson, S. L. Bud'ko, G. Lapertot and P. C. Canfield, *Phys. Rev. Lett.* **86**, 2420 (2001).
6. P. C. Canfield, D. K. Finnemore, S. L. Bud'ko, J. E. Ostenson, G. Lapertot, C. E. Cunningham and C. Petrovic, *Phys. Rev. Lett.* **86**, 2423 (2001).
7. D. R. Armstrong and P. G. Perkins, *J. Chem. Soc Faraday Trans. II* **75**, 12 (1979).
8. J. Kortus, I. I. Mazin, K. D. Belashchenko, V. P. Antropov and L. L. Boyer, preprint, cond-mat/0101446.
9. J. M. An and W. E. Pickett, preprint, cond-mat/0102391.
10. Y. Kong, O. V. Dolgov, O. Jepsen and O. K. Andersen, preprint, cond-mat/0102499.
11. See, Structure Reports for 1953, vol. 17, p. 70; Structure Reports for 1955, vol. 19, p. 74.
12. P. J. Feibelman, J. A. Appelbaum and D. R. Hamann, *Phys. Rev.* **B20**, 1433 (1979).
13. B. N. Harmon, W. Weber and D. R. Hamann, *Phys. Rev.* **B25**, 1109 (1982).
14. D. Bagayoko, G. L. Zhao, J. D. Fan and J. T. Wang, *J. Phys.: Cond. Matt.* **10**, 5645 (1998).
15. G. L. Zhao, D. Bagayoko and T. D. Williams, *Phys. Rev.* **B60**, 1563 (1999).
16. G. L. Zhao and D. Bagayoko, *New J. Phys.* **2**, 16.1–16.12 (2000)
17. D. M. Ceperley and B. J. Alder, *Phys. Rev. Lett.* **45**, 566 (1980).

18. S. H. Vosko, L. Wilk and M. Nusair, *Can. J. Phys.* **58**, 1200 (1980).
19. W. Y. Ching, *J. Amer. Ceramic Soc.* **73**, 3135 (1990).
20. G. F. Koster, *Solid State Physics*, vol. 5, eds. F. Zeitz and D. Turnbull (Academic Press, New York, 1957), p. 173.
21. S. G. Mikhlin, *The Numerical Performance of Variational Methods* (Wolters-Noordhoff Publishing, 1971), Chaps. 1, 2 and 7.
22. S. H. Gould, *Variational Methods for Eigenvalue Problems* (University of Toronto Press, 1957), Chap. 2.
23. G. L. Zhao and D. Bagayoko, accepted for publication in Physica C.
24. G. L. Zhao and J. Callaway, *Phys. Rev.* **B50**, 9511 (1994).
25. P. Ravindran, P. Vajeeston, R. Vidya, A. Kjekshus and H. Fjellvag, preprint, cond-mat/0104253.

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BASIC AND RESEARCH TRAINING FOR THE NEW MILLENNIUM: THE MODEL OF THE TIMBUKTU ACADEMY

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ABSTRACT

We present the activities and some results of a systemic mentoring and research training program known as the Timbuktu Academy. This description of the Academy is intended to stimulate or enable the replication of its 10-point systemic mentoring model. The comprehensiveness and the rigor of the model partly explain its apparent success. One of the distinctions of the pre-college component stems from its production of many African American students who placed themselves among the top 5% or 1% of their classes in the US -- as per national, standardized, academic achievement test scores (*http://www.phys.subr.edu/timbuktu.htm*). More than 50% of the alumni of the undergraduate component pursue advanced degrees, including the Ph.D. in Materials Science and Engineering.

Keywords: *Timbuktu academy; science education; mentoring; educational research; minority community in USA*

INTRODUCTION

Established in 1990, the Timbuktu Academy[1] is a research-based systemic mentoring program at Southern University and A&M College in Baton Rouge (SUBR), Louisiana, USA. Our 10-step systemic mentoring model includes the development and enhancement of the research proficiency of student participants who are referred to as scholars. The specific, *measurable objectives* of the Academy include:

(1) The production of Bachelor degree holders in science, mathematics, engineering, and technology (SMET) disciplines; in the last 10 years, over 90% of these undergraduate scholars have been African American students;

(2) The production and dissemination of new knowledge through research—by the scholars and their research mentors; the mentors are faculty members, and researchers from universities, industry, and

federal laboratories and centers around the country;

(3) The delivery of "educational extension services" to the pre-college, corporate, and other communities, including the enhancement of the academic achievement of 120-200 pre-college students every summer.

In what follows, we refer readers to sources[1-4] that elaborate on the design principles and the paradigm of the Academy. The noted sources also provide a detailed description of the component programs that address various levels of the educational continuum, from elementary school to graduate school and beyond. This presentation focuses on the 10-step systemic mentoring model of the Academy and on illustrative results.

THE TEN-STEP SYSTEMIC MENTORING MODEL OF THE TIMBUKTU ACADEMY

The following listing of the 10-step model of systemic mentoring activities of the Timbuktu Academy, and of the replication of the model through the Louis Stokes Louisiana Alliance for Minority Participation[5] (LS-LAMP), is for the undergraduate level. The same ten (10) steps are applied in the seven (7) pre-college component-programs of the Academy, with a lighter emphasis on items 1 and 6 and with item No. 10 adapted to address the transition from high school to college SMET programs. All ten (10) steps are applied at the graduate school level as well. These activities are keyed to the paradigm of the Timbuktu Academy. Some of them overlap, by design.

1. Financial support is provided to the scholars from *a variety of sources* – The remaining 9 steps of our research-based systemic mentoring model guarantee the use of the resulting *"time dividend"* for studying, research, and related enrichment activities on a full time basis. *According to the law of performance in the Paradigm of the Academy, adequate "time on tasks" is needed to cultivate behavioral, academic or research excellence!* A key to the Timbuktu Academy's success for more than 10 years partly resides in the *diversified funding base* that is apparent in the ACKNOWLEDGMENTS.

2. The enhancement of communication skills is paramount. A host of listening, speaking, reading, writing and related activities are aimed at developing the mastery of the applicable language (English for us) as a vehicle of thought. This activity includes a vigorous exposure to fundamentals of technical communication as provided in *"Writing for Success."*[6] Extensive research report writing and seminar and conference presentations are key means for this enhancement.

3. Comprehensive, scientific advisement is a necessity. The proper sequencing of courses is treated with the utmost care. Indeed, the internal rigidity (or taxonomic structure) of science, engineering, mathematics, and technology (SMET) disciplines requires this approach. Every scholar of the Academy, at or above middle school level, is made to understand the critical need for spending adequate time on learning and research tasks for the cultivation of excellence.[2-4] So, one cannot implement the scientific advisement noted here without first obtaining a *"graduation checkout sheet"!* It lists all the requirements on one to two pages, including the ones announced after the publication of a catalogue! Maintaining a *mentoring portfolio* for each scholar is another critical item for comprehensive advisement. Resume, high school and college transcripts, career goal statements, research reports, etc., are kept in this portfolio. This portfolio is very useful in the writing of substantive letters of recommendation. *It is just an imitation of the meticulous journals we keep for every research project!* Freshman scholars and others are provided with samples of recommendation forms from summer research sites; these forms spell out for them the course taking, communication, behavioral, and other credentials they have to acquire to ensure successful placements!

4. Tutoring is not just for remediation. Tutoring by faculty members and particularly by peers is available to the students or scholars who need it. In fact, regular tutoring areas are often taken over by self-organized study groups! Tutoring is to address deficiencies in a background, to reinforce known essentials, and to promote mastery. Incidentally, tutoring by scholars also promotes their communication skills and their sense of self-worth while they review materials!

5. Generic research activities include rigorous literature searches conducted by the scholars on several subjects. They master sophisticated search algorithms, electronic searches, and related iterations. The scientific literature is an unlimited source of research questions! Refereed literature is the standard for SMET disciplines. Current awareness readings are part of these generic research activities—to follow developments as they occur.

6. Specific research project execution is required for the scholars of the Timbuktu Academy. Faculty members and researchers at federal, industrial, and university laboratories serve as research supervisors and mentors to scholars, year round. The reader should consult the paradigm of the Academy for the need of this exposure. The Academy staff and students work year round to guarantee the placement of all sophomore to senior scholars in competitive research programs during the summer. Several freshmen are placed as well. Assisting scholars to apply vigorously and professionally for these opportunities are related tasks for mentors to accomplish. Success is apparent from the record in Table I.

7. Scholars are immersed in a professional culture. Every scholar is exposed to discussions that explore the dimensions of *ethics in science*. Immersion in a professional culture demands a regular reading of technical journals and appropriate magazines of professional societies, conference attendance, and collaboration with others. Current awareness needs no explanation in an era of information explosion. Professional practices and standards are set and seen in publications, *seminars*, and at conferences. Some group assignments forge an experiential understanding of the value of collaborations. The following specific subcomponents of this step directly address the two summative variables identified by quantitative student-retention models,[7-10] i.e., academic integration and social integration.

- **The weekly seminars** play a crucial role in the development of a professional culture. They repeatedly emphasize the need for superior academic performance and provide a clear road map for any student to make a genius out of himself/herself. Topics that are discussed include *"The Need for Practice in Order to Excel," "How to Study Successfully," "Problem-Solving Proficiency by Design,"*[11] *"The Scientific Method in Practice," "Ethics in SMET," "Thought, Emotion, and Action Management (TEAM),"* a host of *technical research topics*, and the quintessential importance of communication skills. Guest speakers, faculty, and Timbuktu Academy scholars and personnel make presentations at the weekly seminars. These seminars are mandatory. A sense of "belonging" is fostered by these regular seminars; so is social integration.

Table I.

Summer Research by Scholars	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**Totals**
Number of Scholars Placed	18	21	28	40	43	47	39	50	286*
Number of Research Sites	6	12	20	32	33	32	22	32	189*

*Not necessarily distinct students or research sites

Table II.

Conference Participation	1994	1995	1996	1997	1998	1999	2000	2001	Totals
Number of conferences	5	8	10	9	5	6	5	6	54
Number of students attending	58*	34*	126*	67*	11	65*	97*	89*	547*
Number of students presenting	12*	5	9	14*	0	1	3	16*	60*

*Not necessarily distinct students as some students attend more than one conference

- **Participation in local, state, and national conferences** is a critical part of the immersion of the scholars into a professional culture. It addresses horizon-broadening, networking, keeping current, etc. As shown in Table II (above), tens of Academy scholars attend regional and national conferences each year. In addition to the reasons given above, conferences are celebrations of scholarship as explained below!
- **Implicitly and explicitly valuing scholarship is an ongoing process.** A particular event in this pervasive valuing process consists of **the Annual Summer Pre-College Quiz Bowl** and participation in the **National Honda College Quiz Bowl**. In 2000, the SUBR team that placed No. 2 in the nation included a scholar of the Timbuktu Academy (Philip Jones). The importance of a quiz bowl resides in the *celebration of academic excellence*, intellectual prowess and the promotion of scholarship as an integral part of the professional value system.

8. The development and enhancement of computer and technological skills are essential. The mastery of productivity tools, including word-processing, spreadsheets, database, graphics, other application programs, and scientific programming (C++, FORTRAN, etc.) is needed. Advanced exposure has to include a programming language. Practices in environments to which the students are destined, i.e., graduate schools and the global, competitive market, suffice to underscore the need for these enrichment activities.

9. Monitoring throughout the semester prevents potential problems from leading to course grades of F's or to non-executed research tasks. Preventive measures include concentrated efforts, extra-tutoring, and the last resort of dropping a course. The former two steps are best when they are taken as early as possible. The latter step is not an available option past a certain date after mid-term! The monitoring of research participation and performance is critical for another reason: *the development or reinforcement of non-cognitive skills that undergird success (self-discipline, hard work, assiduity, ethical conduct, working well with others, etc.)*. Monitoring and evaluation are part of a professional environment. The noted "Mentoring Portfolio" is maintained for every one of the 50-100 undergraduate scholars and affiliate scholars for the duration of their studies and beyond! Affiliate scholars are not supported financially by the Academy but they participate in all its activities.

10. Guidance to graduate school begins in the freshman year (or earlier) and includes research experiences, conference attendance, *preparation for the Graduate Record Examination (GRE)*, and searches for financial support for graduate studies. Placement in graduate programs follows steps similar to those for summer placement. *Every freshmen is taught that admission into and support by graduate programs and research centers depend on the cumulative grade point average (GPA) for the BS degree, the specific courses taken, research experiences and results, the GRE scores, and meaningful recommendations from mentors and others.*

These points are confirmed by samples of graduate admission application forms provided to the scholars! Similar points relative to college admission are made, in writing, to pre-college students and their parents. In addition, preparation for graduate school includes an understanding of the non-academic factors that are critical to success in graduate school. They include time management, focus, perseverance, etc.

These 10 steps address all four (4) key transition or articulation points. The latter are high school to college SMET, college undecided to college SMET, community colleges to four-year college SMET and college SMET to graduate and Ph.D. programs in SMET. They are rigorously applied from middle school to graduate school, with obvious adjustments for the middle school. They are followed to the letter, as noted above, for undergraduate and graduate students. For high school students, instead of preparing for the GRE, they prepare for the ACT and SAT. We discuss the course taking needed for successful enrollment in college science, mathematics, engineering, and technology (SMET) curricula.

SUMMARY RESULTS OF THE TIMBUKTU ACADEMY

The following illustrative results of the Timbuktu Academy provide an indication of the soundness of its design and the effectiveness of its implementation. *As of the spring of 2001, 106 Academy scholars have earned Bachelor degrees*: 63 in Physics, 19 in Chemistry, and 23 in Engineering. Seventy-eight percent (78%) of Physics scholars have successfully enrolled in or completed graduate school. Over 25% of Physics alumni of the Academy pursue advanced degrees in materials science, including the three (3) in the Ph.D. degree program of the Department of Materials Science and Engineering at the University of Florida in Gainesville. Our graduate school attendance rates are 53% for Chemistry and around 37% for Engineering. The National average for graduate school enrollment of Physics BS holders is 52-60% as per the annual enrollment reports of the American Institute of Physics (AIP). The highest rate of graduate school enrollment by engineering alumni before the establishment of the Academy was 10%. The alumni who do not immediately go to graduate school are

Table III.

African American SMET Graduates Mentored in the Timbuktu Academy and Numbers Who Completed or are in Graduate School

Description	1994	1995	1996	1997	1998	1999	2000	2001	Totals
Physics Alumni	12*	6	10	8	10	8	4	5	63
Enrolled in/completed graduate school	11	3	8	7	8	6	1	5	49
Chemistry Alumni	--	--	3	2	6	5	2	1	19
Enrolled/completed graduate school	--	--	2	0	5	2	0	1	10
Engineering Alumni	2	1	1	2	5	7	4	2	24
Enrolled/completed graduate school	0	0	0	1	3	2	1	2	9

**Includes 1992 and 1993 graduates*

– Not Applicable, Chemistry students were admitted into the Academy starting in 1993-94.

mostly employed by aerospace, defense, automotive, and electronic industries.

Over 800 pre-college students have been mentored from 1996 to 2000 (i.e., last 5 years). About 25% of the elementary to 9th grade students participate for more than a year; hence, the number above (800) stands for about 600 distinct individuals. Details are available at the web site. *The average increase in ACT scores for the high school sophomores to juniors,* as attributable only to the summer programs, ranged from 2.5 to 3.0 points from the summer of 1994 to the summer of 1997. ACT scores are required immediately before and immediately after the participation in the summer programs for high school students. We increased the time devoted to English and Reading in 1998. For that summer (i.e., 1998), we had average increases in the ACT English and composite scores of five (5) and four (4) points, respectively. Some individual scores jumped by as much as 10 points.

As intimated in the abstract, the Timbuktu Academy produced 10 National Merit and National Achievement scholars in 2000. In 2001, it produced 11 semi-finalists who are expected to be finalists (i.e., scholars) after the fall 2001 Scholastic Assessment Test (SAT). The standard-based content and delivery of the academic enrichment activities for these students are believed to ensure their mastery of applicable topics. The demanding schedule of the summer programs, including the daily 6 PM to 9 PM time in study hall, is intended to instill or to enhance good study or research habits.

SUMMARY

The above description of the 10-step systemic mentoring model of the Timbuktu Academy and of LS-LAMP is intended to be a provocative challenge to the Materials Research community to emulate or to replicate this research-grounded program. This replication, we believe, can be adapted to the circumstances of the individual researchers, departments, or centers. Extensive resources, other than the ones noted above, are available to assist prospective mentors.[12-14]

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REFERENCES

1. The Timbuktu Academy (*http://www.phys.subr.edu/timbuktu.htm*), 2001. The very first document at this site provides extensive details on the paradigm and results of the Timbuktu Academy.
2. D. Bagayoko, E. L. Kelley, *The Dynamics of Student Retention: A Review and a Prescription*, Education, **115**, No. 1, 31-39 (1994).
3. Newel, A. and P. S. Rosenbloom, *Mechanisms of Skill Acquisition and the Law of Practice*, in *Cognitive Skills and their Acquisition,* ed. J. R. Anderson, Hillsdale, N. J.: Erlbaum, 1981.
4. K. R. Boof, L. Kaufman, and J. P. Thomas, *Handbook of Perception and Human Performance, Vol. II, Cognitive Processes and Performance*, John Wiley and Sons, New York, New York, 1986, pp 28-71.
5. The Louis Stokes Louisiana Alliance for Minority Participation *(http://www.ls-lamp.org)*. This site also has extensive materials on mentoring SMET majors.
6. O. Plummer and D. Bagayoko, *Writing for Success, a User-Friendly Manual for Effective Communication,"* Publisher: McGraw Hill. ISBN: 0-07-154196-9 (1998).

7. V. Tinto, *Dropout from Higher Education: A Theoretical Synthesis of Recent Research*, Review of Educational Research, **45**, No. 1, 89-125 (1975).
8. E. T. Pascarella and D. W. Chapman, *A Multi-institutional Path Analytic Validation of Tinto's Model of College Withdrawal*, American Educational Research Journal, **29**, No. 1, 87-102 (1981).
9. J. P. Bean, *Conceptual Models of Student Attrition: How theory can Help the Institutional Researcher*, in *Studying Student Attrition*, ed. E. T. Pascarella, Jossey-Bass, 1982, pp 17-33.
10. F. Cabrera, M. B. Castañeda, A. Nora, and D. Hengstler, *The Convergence Between Two Theories of College Persistence*, Journal of Higher Education, **63**, No. 2, 144-163 (1992).
11. D. Bagayoko, E. L. Kelley, and S. Hasan, *Problem-Solving Paradigm*, College Teaching, 2000, pp 24-27.
12. *Perspectives of US Presidential Awardees on Workforce Development*, in *US Science, Engineering, and Technology Workforce of the Future: National Strategy, National Portfolio, National Resource Base*, National Science Foundation (NSF), Washington, D.C., USA, Publication Number: NSF 99-132, 1999.
13. US National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, *Advisor, Teacher, Role Model, Friend: On Being a Mentor to Students in Science and Engineering*, National Academy Press, Washington, D.C., USA, 1997. ISBN 0-309-06363-9
14. D. Bagayoko, R. L. Ford, and E. L. Kelley, *Fundamentals of Mentoring and Networking*, in *Scholarly Guideposts for Junior Faculty*, Publisher: Quality Education for Minority (QEM) Network, 1818 N Street, Washington, D.C., 20036, USA, 1999.

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Electronic structure and charge transfer in 3C- and 4H-SiC

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Abstract. We utilized a local density functional potential, the linear combination of atomic orbital (LCAO) method, and the BZW procedure to study the electronic structure of 3C- and 4H-SiC. We present the calculated energy bands, band-gaps, effective masses of n-type carriers, and critical point transition energies. There is good agreement between the calculated electronic properties and experimental results. Our preliminary total energy calculations for 3C-SiC found an equilibrium lattice constant of $a = 4.35$ Å, which is in agreement with the experimentally measured value of 4.348 Å. The calculated charge transfers indicate that each silicon atom loses about 1.4 electrons that are gained by a carbon atom in both 3C- and 4H-SiC.

1. Introduction

Due to its superior electronic, mechanical and chemical properties, silicon carbide (SiC) has become one of the most promising materials for high-temperature and high-power device applications [1, 2]. The large Si-C bonding energy makes SiC resistant to chemical attack and radiation and ensures its stability at high temperature. SiC is probably the most prominent material that exhibits a wide range of polytypism. More than 200 SiC polytypes have been determined. Among the SiC polytypes, 3C and 4H polytypes are attracting more attention for their favourable electronic properties.

In this paper, we report *ab initio* studies of the electronic structure and charge transfer in 3C- and 4H-SiC. *Ab initio* approaches based on density functional theory, in the local-density approximation (LDA) [3, 4], are well established as very powerful tools for studying properties of semiconductors, metals, surfaces, or interfaces [5, 6, 7, 8, 9]. In these *ab initio* calculations, the exchange–correlation interactions for the many-body electron system are expressed as a functional of the electronic charge density [3, 4, 5].

However, many LDA calculations for semiconductors or insulators often underestimated the band-gaps by 30–50%. Closely related to the band-gap problem, the calculated low energy conduction bands and optical properties of semiconductors—from many LDA computations—also disagree with experimental results. In the case of previous LDA calculations for Ge, several theoretical band structures are metallic [8, 10, 11], in contrast to experimental results. There have been some theoretical efforts intended to address these issues, including calculations that utilize nonlocal, energy-dependent, non-Hermitian self-energy operators [12, 13, 14, 15, 11]. Aryasetiawan and Gunnarsson reviewed several computational approaches, including the GW method, aimed at describing excited state properties [16]. These authors have shown that with converged basis sets and improved exchange and correlation, the calculated band-gap becomes generally correct. Johnson and Ashcroft utilized some simplified applications of the GW method to make scissors-type corrections to the band-gaps of semiconductors [17].

In previous reports [18, 19], Bagayoko and co-workers identified an effect inherent to the variational calculations that utilize a basis set, as done in the LCAO method. This effect is concomitantly due to basis sets and to intrinsic properties of the Rayleigh–Ritz variational approach as explained below. The Rayleigh theorem [20, 23] states that when an eigenvalue equation is solved by the LCAO method, using a basis set of N orbitals and one of $(N + 1)$ orbitals, where the larger set of size $(N+1)$ is obtained by augmenting the smaller one of size N, then the calculated eigenvalues satisfy the following inequalities: $E_1^N \geq E_1^{N+1}$, $E_2^N \geq E_2^{N+1}$, $E_3^N \geq E_3^{N+1}, \ldots$. Succinctly, and provided the above conditions are met, a given eigenvalue is never increased by an increase of the size of the basis set; it either remains unchanged (i.e. if it is equal to the exact value) or is lowered to approach the exact eigenvalue from above. This theorem clearly dictates the use of large basis sets to ensure the convergence of calculated eigenvalues to the corresponding exact ones. Further, completeness consideration requires that the basis sets be as large as possible. Consequently, variational calculations generally place a needed emphasis on ensuring convergence by utilizing large basis sets. The method described below recognizes this requirement and the fact that only the wavefunctions of occupied states are used in the iterative procedure to reconstruct the charge density and the potential. This last fact provides a possible criterion for determining an optimum basis set, i.e. the convergence of the eigenvalues of all the occupied states. This criterion essentially defines the Bagayoko, Zhao and Williams (BZW) procedure that adds to the available approaches for first-principle calculations of properties of materials, with emphasis on the description of excited states and band-gaps.

This procedure has been applied to describe, within the local density approximation, the electronic and optical properties of $BaTiO_3$ [19], wurtzite GaN, Si, diamond (C) and RuO_2 [24]. In this paper, we report our calculations of the electronic properties and charge transfer for 3C- and 4H-SiC, employing the BZW procedure [18, 19, 24].

In the next section, we summarize our computational method. The calculated results are presented in section 3. They are followed by a short conclusion in section 4.

2. Method

Our self-consistent calculations utilized the *ab initio* linear combination of atomic orbital (LCAO) method. These self-consistent LCAO calculations included all electrons and full potentials, without shape approximations. Details of the general computational method are available in previous publications [7, 25, 26, 27, 28, 29]. We employed the Ceperley–Alder type [30] of the local density functional potential as parametrized by Vosko *et al* [31]. The newly developed BZW procedure [18] is employed throughout the calculations. Our calculations are non-relativistic.

Bagayoko, Zhao and Williams (BZW) utilized the criterion discussed above to introduce an *ab initio* procedure for identifying optimal basis sets in variational calculations. Essentially, this procedure requires the performance of three or more self-consistent calculations, beginning with the minimal basis set. The minimal basis set is that required to account for all the electrons of the atomic or ionic species in the material (molecules, clusters, or solids). Every subsequent calculation is carried out with a basis set including that for the previous calculation plus one (or more) orbital of the atomic or ionic species that are present in the material under study. These orbitals are added in the order of increasing energy. Several self-consistent calculations are done until the energies of the occupied states, for calculation N, are the same as those for calculation $(N + 1)$. Then, the material is studied using the basis set from calculation N, known as the optimum basis set. Physically, the BZW procedure defines a new form of convergence, i.e. that of the occupied states (or charge density) with respect to the size of the basis set.

In these calculations for 3C- and 4H-SiC, the atomic wavefunctions were constructed from results of self-consistent *ab initio* atomic calculations. The radial parts of the atomic wavefunctions were expanded in terms of Gaussian functions. Even-tempered sets of Gaussian exponents were employed for both Si and C. The minimum and maximum Gaussian exponents for Si are 0.16 and 0.65×10^5, in atomic units, respectively. The minimum and maximum exponents for C are 0.1 and 0.65×10^5. We included 22 Gaussian orbitals for the expansion of the atomic wavefunctions of the s and p states for Si and C. For the extra atomic wavefunction of Si(3d), we used 18 Gaussian orbitals. We found that the optimal basis set [18, 19, 24] for the LCAO calculations of the electronic structures of 3C- and 4H-SiC consists of the atomic orbitals of Si(1s2s3s4s 2p3p 3d) and C(1s2s3s 2p). Here, Si(4s 3d) and C(3s) represent empty shells in free atoms or ions. They are used to augment the basis set to account for charge redistribution in the solid environment.

3C-SiC (or β-SiC) is the only type of the cubic structure of silicon carbide with a zinc-blende arrangement. In our studies of the electronic structure of 3C-SiC, we used a lattice constant of $a = 4.35$ Å, which is the experimentally measured value. Our calculations of the total energy led to this value as the theoretical one. In the self-consistent calculations of 3C-SiC, we included 28 general k-points in the irreducible Brillouin zone, with proper weights. The computational error for the valence charge was about 0.00056 for 16 electrons. The self-consistent potential converged to about 10^{-5}.

4H-SiC belongs to the C_{6v}^4 group. The atoms of its four 'molecules' are all on the trigonal axes in the special positions of the C_{6v}^4 group:

$$(2a) \quad (0, 0, u); (0, 0, u + 1/2);$$
$$(2b) \quad (1/3, 2/3, v); (2/3, 1/3, v + 1/2)$$

with u(Si) = 3/16, v(Si) = 7/16, and u(C) = 0, v(C) = 1/4. We used the experimental lattice constants of $a = 3.073$ Å, and $c = 10.053$ Å. In the self-consistent calculations of 4H-SiC, we included a mesh of 24 k-points, with proper weights, in the irreducible Brillouin zone. The computational error for the valence charge was about 0.25 for 64 electrons. The self-consistent potentials converged to a difference around 10^{-5} after about 50 iterations. The total number of iterations varies with the input potentials.

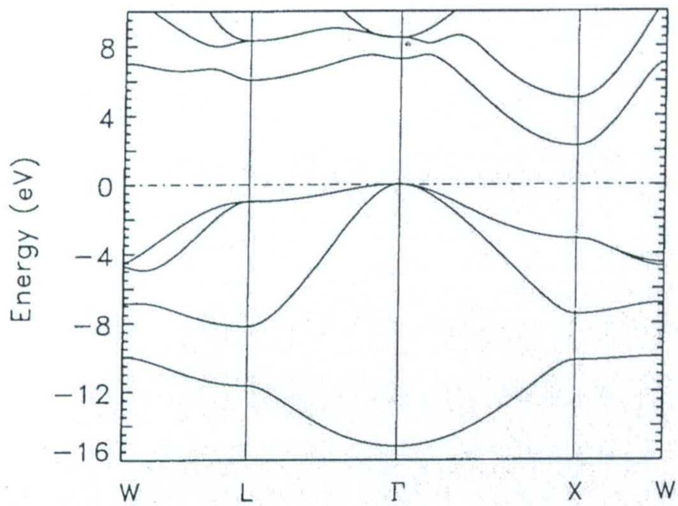

Figure 1. The calculated electronic energy band structure of 3C-SiC along high-symmetry directions, as obtained with the optimal basis set from the BZW procedure.

3. Results

3.1. Electronic structure and total energy of 3C-SiC

The electronic energy bands of 3C-SiC, calculated with the optimal basis set, are shown in figure 1. The zero of the energy is set at the top of the valence band. The top of the valence band of 3C-SiC is at the Γ-point and the lowest conduction band is at the X-point. Our calculated valence bands of the occupied states of 3C-SiC, figure 1, are very close to the previously reported results of *ab initio* LDA calculations [11, 33, 34, 35, 36, 37, 38]. Such agreements are expected from the BZW procedure, since the optimal basis set is the smallest basis set that leads to the same occupied eigenvalues or charge density as all the larger basis sets. The extra lowering of the unoccupied states of the conduction bands, as noted above, is avoided methodologically by the BZW procedure. Comparing our calculated conduction bands in figure 1 with previously reported results for 3C-SiC shows differences that are not a rigid shift of a set of bands with respect to another. These differences between our calculated conduction bands and previous LDA results directly affect the band gap and electron transition energies. Our calculated indirect band-gap of 3C-SiC is 2.24 eV, which is very close to the experimental value of about 2.2–2.4 eV [1, 32]. The previous LDA calculations obtained a theoretical band-gap of about 1.3 eV [33, 11], which was much smaller than experimental results.

Table 1 lists our calculated critical point transition energies of 3C-SiC, along with experimental results. In this table, the indexes v and c refer to the valence and conduction bands, respectively. The experimental transition energies are deduced from the decomposition analysis of the $\epsilon_2(\omega)$ spectrum [41]. Our calculated optical transitions, without any shift, agree well with experimental results. The previously calculated critical point transition energies of 3C-SiC differ with experimental results by about 1 eV [41]. We ascribe the difference between previous LDA results and experiments to the effect circumvented by the BZW procedure as noted above.

Table 1. Comparison of the calculated critical point transition energies (in eV) for 3C-SiC with experimental results. The experimental data are from [41] except where noted otherwise.

3C-SiC	Calculation	Measurements
E_g	2.24	2.2[1] 2.4[32]
$\Gamma_{15}^v \rightarrow \Gamma_1^c$	7.23	7.4
$L_3^v \rightarrow L_1^c$	7.02	7.5
$X_5^v \rightarrow X_1^c$	5.39	5.8
$X_5^v \rightarrow X_3^c$	8.14	8.3±0.1
$\Gamma_{15}^v \rightarrow \Gamma_{15}^c$	8.46	9.0±0.2
$L_3^v \rightarrow L_3^c$	9.27	9.4

Table 2. The effective masses (in m_0) of the n-type carriers at the lowest conduction band of 3C- and 4H-SiC. The theoretical $m_\perp$ of 4H-SiC was calculated as the geometric average of $\sqrt{m_{M\Gamma}.m_{MK}}$.

	Calculation	Measurements
3C-SiC		
$m_{X\Gamma}$	0.72±0.04	$0.677 \pm 0.015(m_{nl})$[42]
m_{XW}	0.22±0.02	$0.247 \pm 0.011(m_{nt})$[42]
4H-SiC		
$m_\perp$	0.41±0.02	0.42[40]
$m_\parallel(m_{ML})$	0.31±0.02	0.33 ± 0.01[46] 0.29[40]
$m_{M\Gamma}$	0.62±0.03	0.58 ± 0.01[46]
m_{MK}	0.27±0.02	0.31 ± 0.01[46]

The effective mass is a measure of the curvature of the calculated bands. The agreement between calculated and measured effective masses indicates an accurate determination of the shape of the bands. Our calculated effective masses of the n-type carriers are listed in table 2. The calculated electron effective mass around the conduction band minimum of 3C-SiC near the X-point is $m_{nl} = 0.72 \pm 0.04 m_0$ for the Γ–X direction, and is $m_{nt} = 0.22 \pm 0.02 m_0$ for the X–W direction. Here, m_0 is the free electron mass. The calculated, anisotropic effective masses are in good agreement with the reported experimental data of $m_{nl} = 0.677 \pm 0.015 m_0$, and $m_{nt} = 0.247 \pm 0.011 m_0$ [42]. The good agreements of the calculated effective mass and the band-gap with corresponding experimental results indicate that the lowest conduction band in figure 1 is reasonably reliable. Our calculated effective masses are not much different from those of previous LDA calculations, indicating that the extra lowering of the conduction bands, in the absence of the BZW procedure, does not seriously affect the shape of these low-energy conduction bands.

The calculated total and partial density of states (DOS) of 3C-SiC are shown in figure 2 and figure 3. From figures 1, 2 and 3, we can see that the lower valence band ranging from −15.2

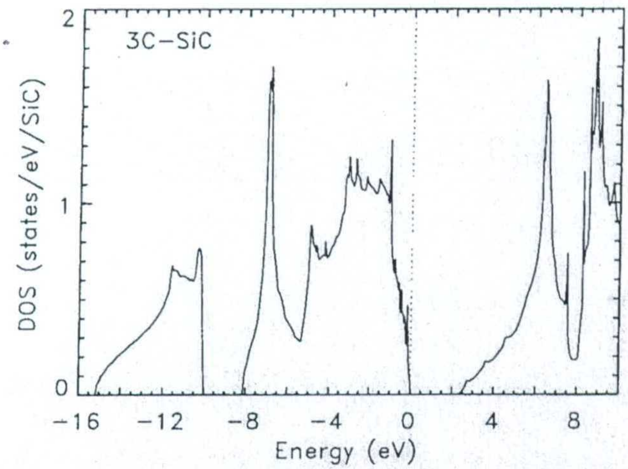

Figure 2. The total density of states (DOS) of 3C-SiC.

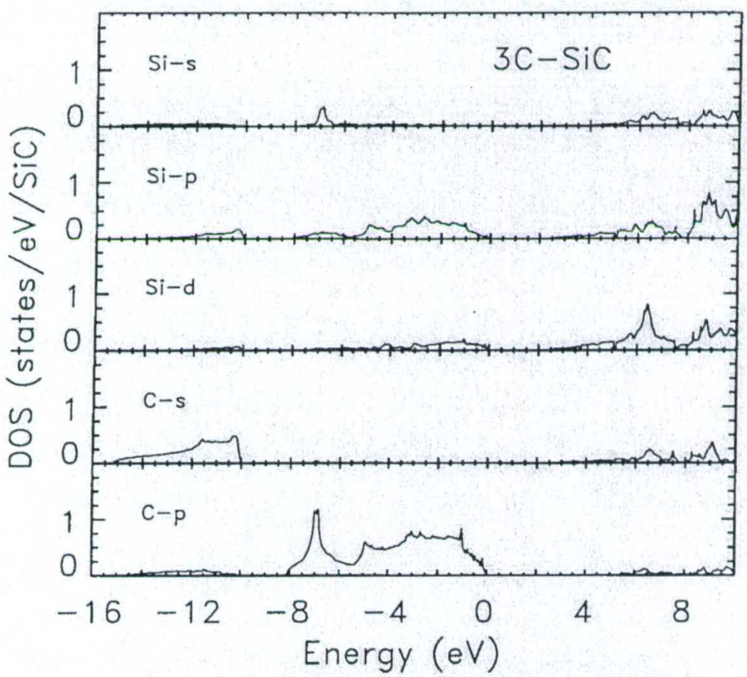

Figure 3. The partial density of states (PDOS) of 3C-SiC.

eV to −10.0 eV is dominated by the C(2s) states that are hybridized with the Si(3p) and C(2p) components. The upper valence bands are dominated by the C(2p) states and strongly hybridized with the Si(3p) states. The Si(3d) bands are highly extended and contribute also to the occupied valence bands in the solid-state environment. The conduction band of 3C-SiC has a long tail, ranging from 2.24 eV to about 5 eV, which is attributed to the wide conduction band around the X-point. In figure 2, the extended tail from the conduction band leads to some experimental complications in determining the exact band gap, including the optical absorption edge which can extend to several tenths of an eV. The total DOS curve in figure 2 shows that the 'practical' [24] and measurable band gap would be about 2.4 eV.

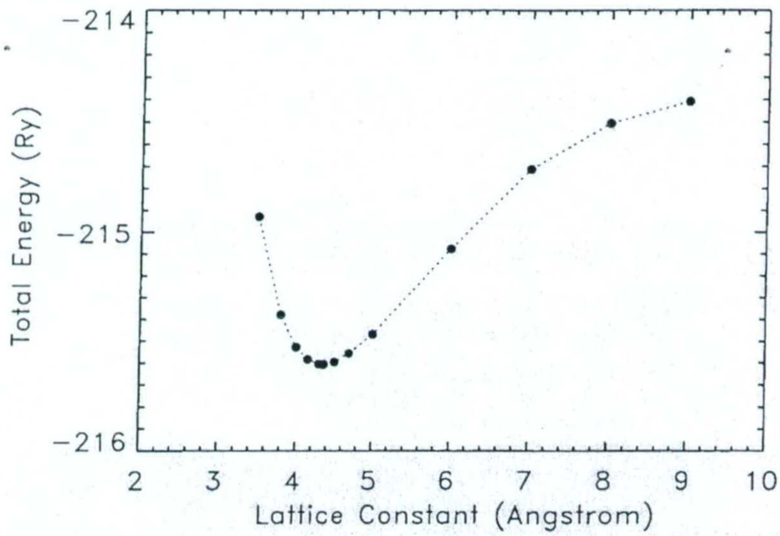

Figure 4. The calculated total energies of 3C-SiC at different lattice constants in the zinc-blende structure. The minimum total energy is located at a lattice constant of 4.35 Å.

An essential, physical quantity in density functional theory is the ground-state total energy of the system. Recently, we have performed preliminary total-energy calculations for the cubic structures of SiC. The calculated total energies for 3C-SiC at different lattice constants are shown in figure 4. The total energies in figure 4 are computed from the electron charge density using the optimal basis set that is identified by the BZW procedure. The calculated equilibrium lattice constant of 3C-SiC, i.e. the value at the minimum of the total energy curve, is 4.35 Å. This value is in excellent agreement with the experimentally measured lattice constant of 4.348 Å[43]. The calculated bulk modulus of 3C-SiC, from the total energy curve in figure 4, is 2.2 Mbar, which also agrees very well with the experimental value of 2.24 Mbar [44].

3.2. Electronic structure of 4H-SiC

The electronic bands of 4H-SiC along some high symmetry lines are shown in figure 5. The notation of the symmetry points in the Brillouin zone follows the convention used by Koster [39]. The highest occupied state of the valence band is at the Γ-point. The conduction band minimum is at the M-point. There is a second minimum of the conduction band at the M-point, which is only 0.18 eV above the lowest unoccupied state. These results are consistent with the ballistic electron emission microscopy study by Kaczer *et al* [45] who observed the second minimum of about 0.15 eV above the lowest conduction band minimum in 4H-SiC. The slight difference between these two minima is attributed to both computational and experimental limitations. These limitations include uncertainties introduced in the fit procedure in the analysis of the experimental data and computational uncertainties that include rounding errors. The indirect band-gap from our calculated electron structure of 4H-SiC is 3.11 eV, which is very close to the experimental data of about 3.2–3.3 eV [1,32].

The calculated effective masses of the n-type carriers around the conduction band minimum of 4H-SiC are also listed in table 2. Our calculated electron effective mass in the plane perpendicular to the c-direction is $m_{\perp} = 0.41 \pm 0.02 m_0$, which agrees very well with the

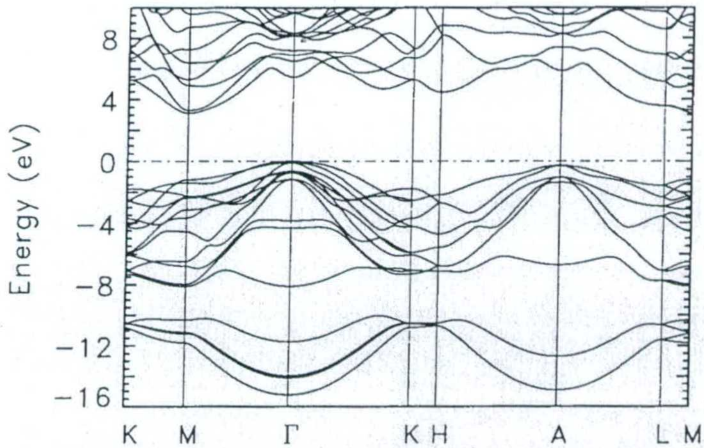

Figure 5. The electronic energy band structure of 4H-SiC along high-symmetry directions, as obtained with the optimal basis set from the BZW procedure.

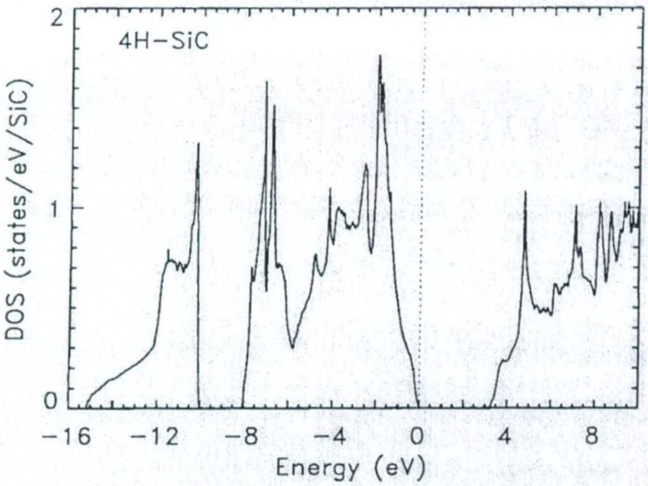

Figure 6. The total density of states of 4H-SiC.

experimentally measured result of 0.42 m_0 [40]. Here, $m_\perp$ is calculated as the geometric average of $\sqrt{m_{M\Gamma}.m_{MK}}$. The calculated effective masses of the n-type carriers in the direction parallel to the c-direction is $m_{ML} = 0.31 \pm 0.02 m_0$, which also agrees well with the experimental results of 0.29–0.33 m_0 [40, 46].

The calculated total and partial density of states (DOS) of 4H-SiC are shown in figures 6 and 7. The density of states of 4H-SiC is very similar to that of 3C-SiC. However, the conduction band edge of 4H-SiC does not have the long tail that that of 3C-SiC does.

3.3. Charge transfer in 3C- and 4H-SiC

Both the silicon and carbon atoms have four valence electrons and prefer a four-fold tetrahedral bond arrangement in the formation of compounds. Charge-transfer properties in SiC are consequently not trivial. We calculated the effective charges and charge transfer for 3C- and 4H-SiC, using the *ab initio* electronic wavefunctions from our computations. Our method

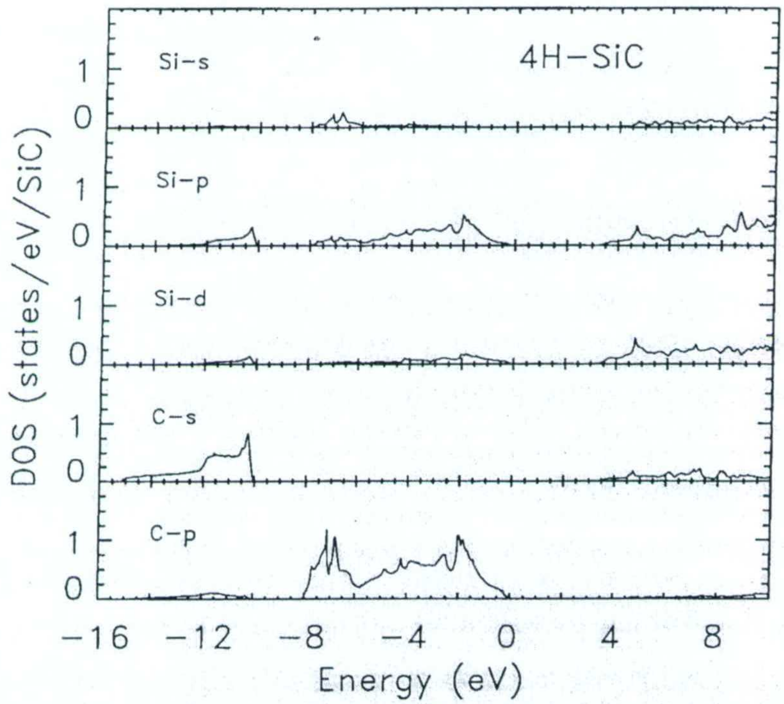

Figure 7. The partial density of states of 4H-SiC.

for calculating the effective charge and charge transfer has been discussed in a previous publication [47].

Our calculated results suggest that the charge transfer in 3C-SiC is very close to that in 4H-SiC, with a difference in the range of computational uncertainty. We found that silicon atoms, in 3C and 4H silicon carbides, give about 1.4 electrons/atom that are gained per carbon atom. The ionic formula for 3C and 4H silicon carbides can be written as $Si^{+1.4}C^{-1.4}$. This result, in retrospect, is understandable in the light of more effective shielding of the nucleus in Si as compared with C. The calculational error for the charge transfer was estimated at about ± 0.1 electrons.

The charge transfer in 3C- and 4H-silicon carbides occurs mainly in the formation of the Si-C bond. In the formation of the Si-C bond in 3C- and 4H-SiC, the charge transfer is about 0.35 electrons/bond, which is very close to the so-called 'one third rule' suggested in the studies of silicon nitride [48, 47].

We also studied the dependence of the charge transfer on the Si-C distance or bond length in 3C-SiC. This dependence is relevant to understanding or simulating the formation of the Si-C bond. We performed *ab initio* self-consistent calculations for several values of the lattice constant. The calculated results for the charge transfers are listed in table 3. Here, we define the bond length as the distance between Si and C when they are the first nearest neighbours. Table 3 shows that the calculated charge transfer, from Si to C atoms in 3C-SiC, remains nearly constant for a substantially large range of the lattice constant or of the bond length. These results support the practice of assuming that the charge transfer in silicon carbides is a constant, as done in molecular dynamical simulations or in calculations of mechanical properties.

Table 3. The calculated charge transfer, from Si to C atoms in 3C-SiC, at different lattice constants and bond lengths.

Lattice constant (Å)	Bond length (Å)	Charge transfer (electrons)
4.35	1.884	1.4
4.50	1.949	1.4
5.00	2.165	1.5
6.00	2.598	1.4
7.00	3.031	1.4
8.00	3.464	1.2
9.00	3.897	1.1

4. Conclusion

We have calculated the electronic structures of 3C- and 4H-SiC, using the *ab initio* LCAO method and the newly developed BZW procedure. Our calculated valence band structures of 3C- and 4H-SiC agree with previous results from first-principle calculations. Our calculated band-gaps, effective masses of n-type carriers, and critical point transition energies agree well with experimental results. Our preliminary total energy calculations for 3C-SiC led to an equilibrium lattice constant of a= 4.35 Å, which is in an excellent agreement with experiment. Our calculated results suggest that the charge transfer in 3C-SiC is very close to that in 4H-SiC. The silicon atoms, in 3C and 4H silicon carbides, give about 1.4 electrons/atom to the carbon atoms. For a substantially large range of the bond length, the calculated charge transfer from Si to C atoms remains nearly constant in 3C-SiC.

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References

[1] See, for example, the review article by Morkoc H, Strite S, Gao G B, Lin M E, Sverdlov B and Burns M 1994 *J. Appl. Phys.* **76** 1363

[2] Katz R N 1980 *Science* **208** 841

[3] Hohenberg P and Kohn W 1964 *Phys. Rev.* B **136** 864

[4] Kohn W and Sham L J 1965 *Phys. Rev.* A **140** 1133

[5] Callaway J and March N H 1984 *Solid State Physics* vol 38 ed H Ehrenreich, D Turnbull and F Seitz (New York: Academic Press) p 135 and references therein

[6] Cohen M L 1993 *Science* **261** 307
[7] Ching W Y 1990 *J. Am. Ceram. Soc.* **73** 3135
[8] Lundqvist S and March N H (ed) 1983 *Theory of the Inhomogeneous Electron Gas* (New York: Plenum) and references therein
[9] Devreese J T and van Camp P 1985 *Electronic Structure, Dynamics, and Quantum Structural Properties of Condensed Matter (NATO Advanced Study Institute. Series B: Physics)* vol 121 (Plenum, New York) and references therein
[10] Bachelet G B and Christensen N E 1985 *Phys. Rev.* B **31** 879
[11] Rohlfing M, Krüger P and Pollmann J 1993 *Phys. Rev.* B **48** 17791
[12] Sham L J and Schlüter M 1985 *Phys. Rev. Lett.* **51** 1418
Sham L J and Schlüter M 1985 *Phys. Rev.* B **32** 3883
[13] Perdew J P and Levy M 1983 *Phys. Rev. Lett.* **51** 1884
[14] Hybertsen M S and Louie S G 1985 *Phys. Rev. Lett.* **55** 1418
Hybertsen M S and Louie S G 1986 *Phys. Rev.* B **34** 5390
[15] Zhu X and Louie S G 1986 *Phys. Rev. Lett.* **56** 2415
[16] Aryasetiawan F and Gunnarsson O 1998 *Rep. Prog. Phys.* **61** 237
[17] Johnson K A and Ashcroft N W 1998 *Phys. Rev.* B **58** 15548
[18] Bagayoko D, Zhao G L and Williams T D 1998 *Bull. Am. Phys. Soc.* **43** 846
[19] Bagayoko D, Zhao G L, Fan J D and Wang J T 1998 *J. Phys.: Condens. Matter* **10** 5645
[20] Gould S H 1957 *Variational Methods for Eigenvalue Problems* (University of Toronto Press) ch 2
[21] Bagayoko D 1983 *Int. J. of Quantum Chem.* **17** 527
[22] Bagayoko D, Lam P M, Brener N and Callaway J 1996 *Phys. Rev.* B **54** 12184
[23] Mikhlin S G 1971 *The Numerical Performance of Variational Methods* (Groningen: Wolters-Noordhoff Publishing) ch 1, 2 and 7
[24] Zhao G L, Bagayoko D and Williams T D 1999 *Physical Review* B **60** 1563
[25] Feibelman P J, Appelbaum J A and Hamann D R 1979 *Phys. Rev.* B **20** 1433
[26] Harmon B N, Weber W and Hamann D R 1982 *Phys. Rev.* B **25** 1109
[27] Zhao G L, Leung T C, Harmon B N, Keil M, Muller M and Weber W 1989 *Phys. Rev.* B **40** 7999
[28] Zhao G L and Harmon B N 1992 *Phys. Rev.* B **45** 2818
[29] Ching W Y, Xu Y, Zhao G L, Wong K W and Zandiehnadem F 1987 *Phys. Rev. Lett.* **59** 1333
[30] Ceperley D M and Alder B J 1980 *Phys. Rev. Lett.* **45** 566
[31] Vosko S H, Wilk L and Nusair M 1980 *Can. J. Phys.* **58** 1200
[32] Landolt-Börnstein New Series III 1987 *Zahlenwerte und Funktionen aus Naturwissenschaften und Technik* ed O Madelung vol 22a (New York: Springer)
[33] Persson C and Lindefelt U 1997 *J. Appl. Phys.* **82** 5496
Persson C and Lindefelt U 1996 *Phys. Rev.* **54** 10257
[34] Chen A and Srichaikul P 1997 *Phys. Status Solidi* b **202** 81
[35] Xu Y N and Ching W Y 1993 *Phys. Rev.* B **48** 4335
[36] Kackell P, Wenzien B and Bechstedt F 1994 *Phys. Rev.* B **50** 10761
[37] Adolph B, Tenelsen K and Bechstedt F 1997 *Phys. Rev.* B **55** 1422
[38] Qteish A, Heine V and Needs R J 1992 *Phys. Rev.* **45** 6534
[39] Koster G F 1957 *Solid State Physics* vol 5 ed F Seitz and D Turnbull (New York: Academic Press) p 174
[40] Son N T, Chen W M, Kordina O, Konstantinov A O Monemar B, Janzen E, Hofman D M, Volm D, Drechsler M and Meyer B K 1995 *Appl. Phys. Lett.* **66** 1074
[41] Lambrecht W R L, Limpijumnong S, Rashkeev S N and Segall B 1997 *Phys. Status Solidi* b **202** 5
[42] Kaplan R, Wagner R J, Kim H J and Davis R F 1985 *Solid State Commun.* **55** 67
[43] Wyckoff R W G 1964 *Crystal Structures* (New York: Wiley)
[44] Landolt-Börnstein New Series III 1982 vol 17a *Zahlenwerte und Funktionen aus Naturwissenschaften und Technik* ed O Madelung (Berlin: Springer)

[45] Kaczer B, Im H J, Pelz J P, Chen J and Choyke W J 1998 *Phys. Rev.* B **57** 4027

[46] Volm D *et al* 1996 *Phys. Rev.* B **53** 15409

[47] Zhao G L and Bachlechner M E 1998 *Phys. Rev.* B **58** 1887

[48] Vashishta P, Kalia R and Ebbsjo I 1995 *Phys. Rev. Lett.* **75** 858
Vashishta P, Kalia R, de Leeuw S W, Greenwell D L Nakano A, Jin W, Yu J, Bi L and Li W 1994 *Comput. Mater. Sci.* **2** 180
Vashishta P, Nakano A, Kalia R and Ebbsjo I 1996 *Mater. Sci. Eng.* **37** B 56

A MATHEMATICAL SOLUTION TO THE BAND GAP PROBLEM

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Using the Rayleigh Theorem, we have resolved the long-standing problem consisting of 30%-50% theoretical underestimates of the band gaps of non-metallic materials. We describe the Bagayoko, Zhao and Williams (BZW) method that rigorously circumvents the basis set and variational effect presumed to be a cause of these underestimates. We present ab-initio computational results that are in agreement with experiment for diamond (C), silicon (Si), silicon carbides (3C-SiC and 4H-SiC), and other semiconductors (GaN, $BaTiO_3$, AlN, ZnSe, ZnO). We illustrate the predictive capability of the BZW method in the case of the newly discovered cubic phase of silicon nitride (c-Si_3N_4) and of selected carbon nanotubes ((10,0) and (8,4)). Our conclusion underscores the inescapable need for the BZW method in ab-initio calculations that employ a basis set in a variational approach. Current nanoscale trends amplify this need. We estimate that the potential impact of applications of the BZW method in *advancing our understanding* of non-metallic materials, in *informing experiment*, and particularly in *guiding device design and fabrication is simply priceless.*

1 Introduction

The fundamental understanding and device applications of carbon-based and other non-metals have suffered from a pervasive inability of ab-initio theoretical calculations to produce accurate *unoccupied energy levels or bands*. The 30%-50% underestimates of the band gaps of these materials[1,2] are just a symptom of presumed, theoretical errors in the unoccupied energies. The inability of these calculations to reproduce measured optical properties of semiconductors is another symptom. Using the Rayleigh theorem[3,4] and the physical content of the Hamiltonian, we describe a basis set and variational effect[5,6,7,8,9,10] that is a source of errors in calculated unoccupied energies of atoms, molecules, clusters, semiconductors and insulators. We present the Bagayoko, Zhao and Williams (BZW) method[5,6,7] that rigorously avoids the above effect and provides a predictive capability for variational calculations that utilize a basis set.

In the remainder of this contribution, we first discuss the persistence of the noted underestimation problem from the advent of quantum calculations to 1998, along with various attempts to solve it. This background is followed by a detailed description of the basis set and variational effect, a presentation of our general method and of the Bagayoko, Zhao and Williams method that resolved the problem. We then present electronic properties for diamond (C), silicon (Si), silicon carbide (3C- and 4H-SiC), barium titanate ($BaTiO_3$), gallium nitride (GaN), zinc oxide (ZnO), and aluminum nitride (AlN). Unlike most previous attempts, particularly the ones utilizing local density functional potentials, our BZW results agree with experiment not only for the unoccupied energy levels and the band gaps, but also for the optical transitions, the dielectric function, and the effective mass. We present our predictions for the electronic and related properties of a newly discovered cubic phase of silicon nitride (c-Si_3N_4) and of selected carbon nanotubes. Our conclusion, in light of the growing trend toward the nanoscale, underscores the need for the BZW method in calculations that employ a basis set in a variational approach of the Rayleigh-Ritz type. It also notes the unavoidable nature of the BZW method for descriptive or predictive computations of properties of nanostructures. This conclusion finally intimates the huge time and money savings that could result from this work – in terms of guiding the design and fabrication of molecular, nanoscale, and other devices.

2 Theoretical Underestimates of Unoccupied Energies

2.1 The Problem: The Unoccupied Energy Problem

"*Calculated Electronic Properties of Metals*"[11] has been available since 1978. In this book, Moruzzi, Janak, and Williams provided the calculated electronic energy bands, charge densities, and related properties of metals. Their results, obtained with density functional potentials, generally agree with experimental measurements and with other theoretical findings. We are not aware of a similar book on semiconductors and insulators. One reason for the absence of such a reference manual stems from the fact that from the dawn of quantum calculations to 1998, there existed no easy way to calculate accurately the unoccupied energy levels of bands of semiconductors or insulators. Indeed, most density functional calculations of electronic properties of these materials, including diamond and other carbon-based systems, led to band gaps that were 30% to 50% smaller than the measured values[1,2,3,4,5,6,7]. *This band gap problem* is actually a symptom of a more general problem stemming from the inaccuracy of the calculated unoccupied energy levels or bands. Such a problem, understandably, reverberates throughout other calculated properties of these systems, including optical transition energies and the dielectric function. The seriousness of this problem may be best understood by noting that most device-utilization of semiconductors or insulators involves excited states. *The unoccupied band problem* has therefore been a major stumbling block to efficient device design and fabrication. Even though it is not as well-known as the *band gap problem*, the above underestimation of unoccupied energies also affected theoretical results for atoms, molecules, and clusters. Additionally, it is pervasive in calculated properties of nuclei in the framework of the shell model.

In the case of semiconductors and insulators, the above problem has been ascribed to limitations of density functional potentials, with emphasis on the local ones. These potentials,[12,13,14,15,16] from the early 1970's to present, continue to be extensively utilized in theoretical descriptions of many body systems. Other approaches to the representation of the potential, i.e., those based on Hartree Fock formalism, did not resolve the problem and are often accompanied by other difficulties. For instance, the limitations of the Hartree Fock method are described by Callaway;[17] they include inordinately large band widths.

2.2 Attempts to resolve the problem

Several approaches have been utilized in an attempt to remedy the theoretical underestimation of unoccupied energy levels or bands. They included the use of density functional potentials that are non-local, as done in the generalized gradient approximation (GGA).[14] Some approaches applied the "*scissors approximation*" to unoccupied bands obtained with local density functional potentials.[18] This approximation essentially consists of rigidly shifting upward the calculated unoccupied energy levels or bands.[18] The self-interaction correction (SIC) and the self-interaction with relaxation correction are other approaches[2] that have been tried with limited success. Perhaps one of the most widely used approach that clearly goes beyond density function theory is the dressed Green function (G) and screened Coulomb (W) interaction formalism that employs non-local, energy-dependent, and non-Hermitian operators. This GW method[1] is perhaps the most successful of the ones referenced above, even though it also has its limitations. In particular, the GW method tends to give band gaps that are slightly larger than the experimental values. Many GW calculations are not self-consistent; the self-consistent ones are reported[19] to increase the overestimation of the band gaps of semiconductors and insulators.

In 1998, we had obtained calculated energy bands that reproduced experimentally measured properties, including the band gap, optical transition energies, and the dielectric function of barium titanate.[5,6] The extent of this agreement with experiment, for all calculated properties, warranted a search for an explanation; luck and over-complete or incomplete basis sets were not satisfactory explanations – in light of the pervasiveness of the agreement with experiment. Our prior experiences with calculations with several basis sets of different sizes[9] led us to the explanation of the relative positions of the conduction bands as compared to the occupied bands. In particular, Bagayoko had utilized[9] the Rayleigh theorem to explain the rigid shift of band energies, up or down, depending on whether the basis size is reduced or enlarged, respectively. We identified and characterized a basis set and variational effect that explains most of the *unoccupied energy problem*. This effect is described in the next section.

2.3 An explanation of the problem: a basis set and variational effect

It has been explained[7] that in a typical ab-initio, self-consistent calculation that employs the linear combination of atomic orbital method, electronic eigenfunctions are expanded using basis sets derived from atomic calculations[9,17]. Charge densities and potentials are constructed *using only the functions belonging to occupied states.*[17] The Hamiltonian matrix is generated and diagonalized. Key output quantities are discrete energy levels or continuous bands and related wave functions. The resulting output wave functions for the occupied states are employed to generate a new charge density and the computations are repeated. The process of using the output of iteration (n) – *for occupied states* – to construct the input for iteration $(n+1)$ continues until self-consistency is reached. Various measures are utilized to define self-consistency, i.e., when basic quantities, including charge densities, potentials, eigen-energies, etc., are respectively unchanged from one iteration to the next.

The trial basis sets are found by various authors by augmenting the atomic orbitals with polarization and diffuse orbitals[7] whose numbers, until the work of Bagayoko, Zhao and Williams,[5,6,7] had no particular limit. In fact, from a completeness standpoint, the larger these numbers the better, provided no "catastrophic sinking of energy levels" or negative Millican population numbers occur for occupied states.[20]

The above arbitrariness in the selection of the size of the basis set, by virtue of the Rayleigh theorem and the use of the wave functions for the occupied states to generate the Hamiltonian, leads straightforwardly to the basis set <u>and</u> variational effect noted above. Indeed, the Rayleigh theorem states that when an eigenvalue equation is solved using a basis set of dimension N and one of dimension $N+1$, such that all the orbitals in the first basis are included in the second, larger one, then the eigenvalues resulting from the calculation with $(N+1)$ orbitals will be respectively lower or equal to their corresponding ones from the calculation with N orbitals. Specifically, if the eigenvalues in each calculation are ordered from the lowest to the highest, then $E_1^{N+1} \leq E_1^N$, $E_2^{N+1} \leq E_2^N$, $E_3^{N+1} \leq E_3^N$, etc. Physically, these inequalities indicate that a given variational eigenvalue approaches the corresponding exact eigenvalue from above.

Clearly, the above theorem suggests that calculations should employ basis sets that are as large as possible. This fact and the preoccupation with ensuring the quantum mechanical completeness of the basis set partly explain the reason that the following effect was not quantitatively circumscribed for many decades. (The rather vague expression of "basis set effects" is not to be confused with the basis set and variational effect as defined and circumscribed herein using a mathematical theorem.) A fact that places a limit on the size of basis sets in variational calculations, however, stems from the *utilization of the wave functions of the occupied states to generate the charge density, the potential, and the Hamiltonian matrix*. This matrix contains the physics of the calculations. We define a minimal basis set as one that contains just enough orbitals to account for all the electrons in the system under study. Beginning with a minimal basis set, if one performs several calculations with basis sets that are each obtained by augmenting the previous, smaller one, then one is expected to reach a size such that the charge density, the potential, and the Hamiltonian no longer change. One does. Past this point, the use of larger basis sets, by virtue of the Rayleigh theorem, will still lead to a lowering of some unoccupied energy levels or bands, even though the occupied ones no longer change. *There lies the basis set and variational effect, i.e., the extra lowering of some unoccupied energy levels of bands, by virtue of the Rayleigh theorem,*[3,4,9] *when unnecessarily large basis sets are employed in self-consistent variational calculations of the Rayleigh-Ritz type.*

To facilitate the forthcoming presentation of the Bagayoko, Zhao and Williams (BZW) method for avoiding this effect, we define the *optimal basis set* of dimension N as that of the first of the calculations, with increasing basis sets, such that the next calculation produces the same charge density, potential, Hamiltonian, and occupied energy levels or bands. *This optimal basis set* defines a new form of convergence, i.e., that of the Hamiltonian and of the occupied energy levels or bands vis-à-vis the dimension of the basis set. It was shown[7] that calculations with basis sets larger than the optimal set, if otherwise done correctly, do not change the charge density, the potential, the Hamiltonian, or the occupied energies. They do continue indefinitely to lower some unoccupied energies, given that the fundamental theorem of algebra dictates the appearance of new eigenvalues upon the increase of the size of the basis set or of the dimension of the Hamiltonian matrix.

3 Method

3.1 General method: the potential and the formalism

The general method employed in our calculations has been extensively described in the literature.[5,6,7,8,9,10] Our self-consistent, computational formalism consists of the linear combination of atomic orbitals (LCAO). We employed the electronic structure package of the group of Professor Bruce Harmon at the Department of Energy (DOE) Laboratory at Iowa State University.[21,22] We utilized Gaussian orbitals and therefore refer to our approach as a linear combination of Gaussian orbitals (LCGO). In describing many body system, the choice of the potential is a critical one. In all the calculations discussed below, we used the Ceperley-Alder type[15] of local density potentials as parameterized by Vosko, Wilk and Nusair.[16]

3.2 The Bagayoko, Zhao and Williams (BZW) method

We introduced this method in 1998 for completely circumventing, from first principle, the above identified basis set and variational effect. The BZW method basically requires a minimum of three self-consistent calculations that utilize basis sets of different sizes. It begins with the minimum basis set, i.e., the basis set needed to account for all the electrons of the atomic or ionic species that are present in the molecule, cluster, or solid under study. Completely self-consistent calculations are carried out. For the second calculation, the minimal basis set is augmented with one or more atomic orbitals that belong to the next and lowest lying energy levels in the atomic or ionic species. The self-consistent bands from calculations I and II are compared, graphically and numerically. In general, there will be qualitative (shape and branching) and quantitative (numerical values) differences between the occupied bands from calculations I and II. A third calculation is performed, using the basis set for calculation II as augmented with orbitals representing the next lowest-lying atomic energy levels.

The above process is continued until the comparison of the occupied energy levels leads to no qualitative or quantitative difference. When the results (i.e., occupied energies only) from calculation N and those from calculation $(N+1)$ agree within the computational error, then the optimum basis set is that of calculation N. This selection rests on the fact that a lowering of unoccupied levels, as in calculation $(N+1)$, after the occupied levels converged with respect to the size of the basis set, as in calculation N, is dictated by the Rayleigh theorem and does not necessarily reflect the physics of the system. Such a lowering may not be the manifestation of any fundamental interaction, but rather the expression of the basis set and variational effect identified above. In fact, it was shown[7] that calculation $(N + 1)$ and others with larger basis sets do not change the self-consistent charge density or potential from their values as obtained in calculation N that utilized the optimal basis set. In multi-species systems like GaN, two or more orbitals may be added at a time if the affected atomic levels are close in energy. While we utilized the occupied energy bands for the determination of convergence with respect to the size of the basis set, other parameters could be employed. They may include the charge density for occupied states and particularly the potential.

3.3 Computational details

This paper is intended to present the essentials related to the BZW method, as done above, and the related results for a variety of materials. Consequently, we refer the reader to previous publications[6,7,8,10,23] that provide extensive computational details for each material. In particular, lattice structures, specific lattice parameters, the various s, p and d orbitals included in the calculations, and the numbers of iterations are among these details. We discuss both the angular and radial components of these orbitals.

4 Results: Calculated Electronic Properties of Non-Metals

We list in Tables 1 and 2 the calculated band gaps of diamond, 3C- and 4H-SiC, and of several other semiconductors. Space limitation does not allow us to delve into the details of these results and of many others that are available in our previous publications.[6,7,8,9,10] For each material listed below, the reader should refer to these sources[6,7,8,9,10,23,24,25] for details. Other results in these papers include the electronic energy bands, the density of states, effective masses, charge transfers, contour plots of charge densities, and optical transition energies. For $BaTiO_3$ and 3C-SiC, we provided the dielectric function and the total energy curves, respectively.

The verified theoretical predictions[26,27] of Dr. Carter T. White's group at the Naval Research Laboratories (NRL) on properties of carbon nanotubes partly inspired our interest in these materials. We report below the band gaps for carbon nanotubes (10,0) and (8,4). Carbon nanotubes (10,0) belong to a symmorphic group. Its diameter is 7.83 Å and there are 40 atoms in the unit-cell. Carbon nanotube (8,4) belongs to a nonsymmorphic group. The

Table 1. Calculated electronic properties (i.e., band gaps) of selected carbon-based and other semiconductors versus measured values. All the calculations employed the BZW method. The results below are therefore obtained with the optimal basis sets for the affected materials. Data for c-Si_3N_4 and for carbon nanotubes (8,4) and (10,0) are predictions. Further details are available in the identified publications. The symbol Eg stands for the band gap. Effective masses, M^*, have symmetry and directional (parallel and perpendicular) labels as subscripts. The free electron mass is m_0. Energies are in electron volts (eV). The concept of practically measurable band gap has been explained elsewhere,[7] as per tail structures in the density of states. When a range is provided for the theoretical band gap, the lower limit indicates the theoretical minimum gap while the upper limit shows the largest experimental value, depending on the sensitivity of measurement instrument and method and of subsequent analysis. The Table is continued in Table 2.

	Calculation	Measurement
$BaTiO_3$ (Ref.6)		
Eg	2.6 eV	2.8, 3.0 eV
$M^*_{p,\parallel}$	7.5 m_0	very anisotropic
$M^*_{p,\perp}$	1.2 m_0	
$M^*_{n,\parallel}$	3.4 m_0	
$M^*_{n,\perp}$	1.2 m_0	1.0 - 1.5 m_0
GaN (Ref.7)		
Eg	3.4 eV	$\sim$ 3.4 eV
M^*_n	0.22 $\pm$ 0.03 m_0	0.2 $\pm$ 0.02 m_0
Si (Ref.7)		
Eg	1.02 eV	1.14, 1.17 eV
Band width (valence)	12.1 eV	12.5 eV
M^*_{nt}	0.20 $\pm$ 0.03 m_0	0.19 m_0
M^*_{nl}	0.93 $\pm$ 0.03 m_0	0.98 m_0
ZnO		
Eg	3.2 eV	3.4 eV
AlN (Ref.24)		
Eg	5.5 - 6.2 eV	3.9 - 6.2 eV
Carbon nanotube (8,4)		
Eg	0.90 eV	Unknown to us

diameter of (8,4) nanotube is 8.29 Å. The chiral angle of (8, 4) relative to the zigzag direction is 19.1°. There are 112 atoms in its unit-cell. While (10,0) has a direct band gap of 0.95 eV at the gamma point, the 0.9 eV gap of (8,4) is off the gamma point. The highest energy state of the valence band and

Table 2. Continuation of Table 1.

	Calculation	**Measurement**
Diamond (C) (Ref.7)		
Eg	5.05 eV	5.3, 5.48 eV
W_v (valence band width)	21.35 eV	21± 1 eV, 24.2 eV
$M^*_{n,\parallel}$	$1.1 \pm 0.2\ m_0$	$1.4\ m_0$
$M^*_{n,\perp}$	$0.30 \pm 0.03\ m_0$	$0.36\ m_0$
3C-SiC (Ref.8)		
Eg	2.24 eV	2.2, 2.4 eV
M^*_x	$0.72 \pm 0.04\ m_0$	$0.677 \pm 0.015\ m_0$
M^*_{xw}	$0.22 \pm 0.02\ m_0$	$0.247 \pm 0.011\ m_0$
4H-SiC (Ref.8)		
Eg	3.11 eV	3.2, 3.3 eV
$M^*_{n,\perp}$	$0.41 \pm 0.02\ m_0$	$0.42\ m_0$
$M^*_{n,\parallel}$	$0.31 \pm 0.02\ m_0$	$0.33, 0.29\ m_0$
$M^*_{M\Gamma\vert}$	$0.62 \pm 0.03\ m_0$	$0.58 \pm 0.01\ m_0$
$M^*_{MK\vert}$	$0.27 \pm 0.02\ m_0$	$0.31 \pm 0.01\ m_0$
c-Si_3N_4 (Ref.23)		
Eg	3.68 eV	(Not yet available)
ZnSe (Ref.25)		
Eg	2.6 - 3.1 eV	2.8 eV
Carbone nanotube (10,0)		
Eg	0.95 eV	Unknown to us

the lowest state of the conduction band are located at about $0.07X$, where $X = (1,0,0)\frac{\pi}{a}$. These nanotube band gaps, and that of 3.68 eV for the newly discovered cubic phase of silicon nitride (c-Si_3N_4), are predictions – given that we are unaware of any available experimental values, to date.

5 Conclusion

As per the above results and others, the described BZW method resolved the long standing theoretical underestimation, by 30% -50%, of the band gaps of semiconductors and insulators, included carbon-based materials and carbon nanotubes. As such, the method provides a tool for significant contributions of theoretical calculations in (a) the correct description of non-metallic materials, (b) the predictions of electronic, optical, and related properties of semiconductors, (c) industrially relevant band gap engineering and related design and fabrication of devices, and (d) the search for novel materials. In particular, current trends toward the nanoscale, in light of the prevailing nature of quantum effects at the atomic and molecular levels, seem to dictate the use of this method for computations that utilize basis sets in a variational approach of the Rayleigh-Ritz type.

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References

1. A. Rubio, J.L. Corkill, M.L. Cohen, E.L. Shirley and S.G. Louie, *Phys. Rev.* **B48**, 11810 (1993).
2. D. Vogel, P. Kriiger and J. Pollmann, *Phys. Rev.* **B55**, 12836 (1997).
3. S.H. Gould, *Variational Methods for Eigenvalue Problems* (University of Toronto Press, Toronto, Canada, 1957), Chapter 2.
4. S.G. Mikhlin, *The Numerical Performance of Variational Methods* (Wolters-Noordhoff, Groningen, 1971), Chapters 1, 2 and 7.
5. D. Bagayoko, G.L. Zhao and T.D. Williams, *LDA prediction of electronic properties of* $BaTiO_3$, *Bull. APS* **43 (1)**, 846 (1998).
6. D. Bagayoko *et al.*, *Ab-initio calculations of the electronic structure and optical properties in ferroelectric tetragonal* $BaTiO_3$, *Journal of Physics: Condensed Matter* **10**, 5645 (1998).
7. G.L. Zhao, D. Bagayoko and T.D. Williams, *Local density functional prediction of electronic properties of GaN, Si, C, and* RuO_2, *Phys. Rev.* **B60**, 1563 (1999).
8. G.L. Zhao and D. Bagayoko, *Electronic structure and charge transfer in 3C- and 4H-SiC*, *New Journal of Physics* **2**, 16.1-16.12 (2000), `http://www.njp.org`.
9. D. Bagayoko, *Contraction of gaussian basis sets and the total energy*

of *FCC copper*, *Int. J. of Quantum Chemistry: Quantum Chemistry Symposium* **17**, 527 (1983).

10. D. Bagayoko and G.L. Zhao, *Predictive ab-initio computations of properties of ferroelectric materials*, *Int. Jour. Mod. Phys.* **B13**, 3767 (1999).
11. L. Moruzzi, J.F. Janak and A.R. Williams, *Calculated Electronic Properties of Metals* (Pergamon, New York, 1978).
12. H. Hohenberg and W. Kohn, *Phys. Rev.* **136**, 3864 (1964).
13. W. Kohn and L.J. Sham, *Phys. Rev.* **140**, A1133 (1965).
14. J. Perdew and A. Zunger, *Phys. Rev.* **B23**, 5048 (1981).
15. D.M. Ceperley and B.J. Alder, *Phys. Rev. Lett.* **45**, 566 (1980).
16. S.H. Vosko, L. Wilk and M. Nusair, *Can. J. Phys.* **58**, 1200 (1980).
17. J. Callaway, *Quantum Theory of the Solid State*, Second Edition (Academic Press, Boston, 1991).
18. K.A. Johnson and N.W. Ashcroft, *Phys. Rev.* **B58**, 15548 (1998).
19. W.-D. Schöne and A.G. Eguiluz, *Phys. Rev. Lett.* **81**, 1662 (1998).
20. D. Bagayoko *et al.*, *3d impurities in aluminum*, *Phys. Rev.* **B54**, 12184 (1996).
21. B.N. Harmon, W. Weber and D.R. Hamann, *Phys. Rev.* **B25**, 1109 (1982).
22. G.L. Zhao *et al.*, *Phys. Rev.* **B40**, 7999 (1989).
23. D. Bagayoko and G.L. Zhao, *Predicted electronic properties of cubic silicon nitride (c-Si_3N_4)*, to appear in *Physica C* (2001).
24. Y. Luo, *Ab-Initio Computation of the Electronic Structure of Wurtzite Aluminum Nitride*, Master's Degree Thesis in Physics, Southern University and A&M College, Baton Rouge, Louisiana, 70813, USA (2000).
25. L. Torrence, *The BZW Method and the Electronic Properties of Zinc Selenide (ZnSe)*, Master's Degree Thesis in Physics, Southern University and A&M College, Baton Rouge, Louisiana, 70813, USA (2001).
26. C.T. White and J.W. Mintmire, *Density of states reflects diameter in nanotubes*, *Nature* **394**, 29 (1998).
27. J.W. Mintmire and C.T. White, *Universal density of states for carbon nanotubes*, *Phys. Rev. Lett.* **81**, 2506 (1998).