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Challenges and opportunities in developing STEM curricula for tertiary institutions in Africa: Materials Science and Engineering at AUST-Abuja

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Kwadwo Osseo-Asare, Distinguished Professor of Materials Science and Engineering and of Energy and Geo-Environmental Engineering, has been a Penn State faculty member for the last thirty-six years. Prior to this he spent one and a half years as a research metallurgist and project leader with AMAX Extractive Metallurgy Lab (Golden, CO) working on a variety of industrial research projects in hydrometallurgy. Osseo-Asare has made many pioneering contributions to aqueous processing research and technology. He and his coworkers presented the most comprehensive set of aqueous stability diagrams for hydrometallurgical processing (including ammonia and cyanide leaching systems, where they are used in industrial operating manuals). He is a world leader on the interfacial aspects of dissolution and solvent extraction. He and his students made seminal contributions to microemulsion-mediated synthesis of nanoparticles. His research work has been recognized by several awards, including election to the National Academy of Engineering (2004), for "contributions to the fundamental understanding of interfacial phenomena in leaching and solvent extraction"; the Milton E. Wadsworth Extractive Metallurgy Award (2005), Society for Mining, Metallurgy, and Exploration (SME), for "notable contributions in the field of hydrometallurgy which have furthered the science and engineering of metallurgical processing"; Penn State's Faculty Scholar Medal for Engineering (1999), for providing "significant insight into dissolution and precipitation reactions occurring during water processing of metals and ceramic powders, and in chemical-mechanical polishing in the microelectronics industry"; James Douglas Gold Medal (1997), American Institute of Mining, Metallurgical, and Petroleum Engineers (AIME), for "research contributions to the fundamental understanding of interfacial phenomena in leaching, solvent extraction, and particle synthesis."

He has held numerous visiting professorships and fellowships at JSPS Fellow, Kyushu Univ., Japan, Dec. 2011; African University of Science and Technology (AUST), Abuja, Nigeria, 2008-; Department of Materials Science and Engineering, Faculty of Engineering Sciences, University of Ghana, Jan.-July, 2008; Federal University of Minas Gerais, Department of Metallurgical and Materials Engineering, Belo Horizonte, Brazil, Aug.-Dec., 2007; Martin Luther King, Jr. Visiting Professor, Department of Materials Science and Engineering, Massachusetts Institute of Technology (MIT), Cambridge, MA, Aug. 2000-July 2001; Institute for Advanced Materials Processing, Tohoku University, Sendai, Japan, May-October 1993; Institute of Mining and Mineral Engineering, University of Science and Technology, Kumasi, Ghana, Sept. 1992-Feb. 1993; Academic Visitor, Department of Chemical Engineering, Imperial College, London, U. K., Jan.-June, 1985. Prof. Osseo-Asare has contributed to the following books: K. Osseo-Asare and J. D. Miller, eds., Hydrometallurgy-Research Development and Plant Practice, TMS-AIME, Warrendale, PA, 1982; United Nations, Analysis of Processing Technology for Manganese Nodules, Seabed Minerals Series, Vol. 3, Graham & Trotman, London, 1986 (K.O.A. co-author); K. Osseo-Asare, Aqueous Processing of Materials: Unit Processes with Applications to Hydrometallurgy, Materials Processing, and Environmental Systems, Academic Press/Elsevier, an undergraduate-level textbook, in preparation – draft chapters used at Dept. of Chemical Eng., University of Toronto, Dept. of Materials Sci. and Eng., MIT (http://www.allbookstores.com/author/Kwadwo_Osseo-Asare.html); K. Osseo-Asare, Chemical Principles in Aqueous Processing of Materials. Hydrometallurgy, Materials Processing, and Environmental Systems, a graduate-level textbook, in preparation - draft chapters used at UC Berkeley. From 1998- 2010 he served as Editor-in-Chief, Hydrometallurgy, International Journal of Aqueous Processing. He has served as a member, Visiting Committee, Division of Materials Science and Engineering, Boston University since 2009. He is been an International Associate, National Institute of Science and Technology for Mineral Resources, Water, and Biodiversity, Federal University of Minas Gerais (UFMG), Belo Horizonte, Brazil (INCT Acqua; since 2009. He writes a blog on AqueouSolutions (http://www.aqueousol.blogspot.com). Sample postings include the following: If You Educate a Girl, Part IX, Aug. 8, 2011. Minerals as Materials, Materials as Minerals, Part 2, Feb. 1, 2010. Conversations about Mineral Industry Education: Prof. Richard Amankwah of UMaT, Ghana, July 13, 2009. Materials Science and Engineering, or Nothing Else, April 14, 2009. Materials Society of Nigeria, April 5, 2009.

African Proverbs—Teaching and Learning Materials Science and Engineering, April 3, 2009. Ghana Materials Industry, Part 4, March 7, 2009. Douglas Fuerstenau: Giant of Minerals/Materials Processing, Dec. 15, 2008. Ghana and South Korea: The Past Does Not Predict the Future? Oct. 17, 2008. Ant Hills: Materials Science and Engineering, Aug. 12, 2008. Prof. Oseo-Asare recieved his education & training at the University of California (Berkeley), Department of Materials Science and Engineering, B.S. (with Honors, Department Citation for Outstanding Undergraduate Achievement), 1970; M.S., 1972; Ph.D., 1975.

Dr. Victor A Atiemo-Obeng, The Dow Chemical Company (Retired)

Victor A. Atiemo-Obeng, PhD, FAIChE

Victor Atiemo-Obeng is passionate about most effective engineering science research and practice. For the last six months of 2012, Victor served as Director and Interim Country Manager, Ghana for Dow Chemical West Africa LLC. He had retired at the end of January 2012 after nearly 34 years of meritorious service at the rank of Dow Fellow, one of the top 100 technical staff of The Dow Chemical Company, the biggest chemical company in North America. He was on the leadership team of the Engineering & Process Sciences Department of the company's Core R&D function. He had served on the leadership team of Fluid Mechanics & Mixing discipline within the Research & Engineering Sciences. Victor leveraged his leadership skills and technical expertise to develop and successfully commercialize processes across a wide range of Dow's businesses. He was the lead process engineer for several multimillion-dollar capital projects that received Dow's Global Engineering Excellence Awards. He was also a key contributor to the company's Global Project Methodology and the Scale-up Checklist. During his co-leadership of the Global Mixing Emphasis Team his early course on "Mixer Selection, Scale-up and Design" was developed into the Dow Mixing Manual and Mixing Course. Victor served for many years on the Executive Council of the North American Mixing Forum (NAMF), a division of the American Institute of Chemical Engineers (AIChE). While in that capacity, he was invited to be co-editor as well as contributing author of several chapters of the world-acclaimed "Handbook of Industrial Mixing: Science and Practice" published in 2004 by John Wiley & Sons, Inc. In support of Dow's commitment to achieving a diverse work force, Victor co-created the award-winning Building Engineering and Science Talent (BEST) Symposium at Dow to introduce doctoral and post-doctoral scientists from U.S. ethnic minority groups to the wide range of industrial R&D opportunities at Dow. Invited by the Board on Chemical Sciences and Technology, National Academies, he contributed to the workshop and publication of "Sustainability in the Chemical Industry: Grand Challenges and Research Needs - A Workshop Report (2005). He has also served under the auspices of AAAS as a judge for the US EPA P3: "People, Prosperity and the Planet Student Design Competition for Sustainability" in 2009, 2010, 2011 and 2012. Victor has been a visiting professor to the African University of Science and Technology (AUST) in Abuja Nigeria since May of 2011. He has taught courses in Probability, Statistics and Design of Experiments as well as in Materials Process Engineering. In the late seventies Victor worked as a Research Scientist for the Council for Scientific and Industrial Research (CSIR) in Ghana. He was invited to represent Ghana at the first Economic Commission for Africa (ECA)/United Nations Industrial Development Organization (UNIDO) Meeting of Experts on Chemicals held in Addis Ababa in November 1979. Victor is a Fellow of AIChE, where he has served as national nominating committee member and as Director and past Chair of the Mid-Michigan local chapter. He remains a member of AIChE, NAMF, the National Organization for the Professional Advancement of Black Chemists and Chemical Engineers (NOBCChE), the American Chemical Society (ACS) and the American Society for Engineering Education (ASEE). Victor's accomplishments have been have been recognized with the AIChE-NAMF Award for Excellence in Mixing Research and Practice, Dow Technology Centers' Technology Improvement Award, the Dow Chemical Company's Michigan Consultants Award for Technical Excellence, AIChE Mid-Michigan section's Chemical Engineer of the Year, NOBCChE's Percy Julian Award, The Dow Chemical Company President's Community Service Award, and The Martin Luther King Jr. Recognition Award. Victor Atiemo-Obeng joined Dow in 1975 in the Process Development Department of Michigan Operations R&D after obtaining a PhD in Chemical Engineering from the University of Wisconsin, Madison. He left Dow and went back to his home country of Ghana in 1977, but returned in 1980.

Challenges and opportunities in developing STEM curricula for tertiary institutions in Africa: Materials Science and Engineering at AUST-Abuja

ABSTRACT

Recent high GDP growth rates and increasing foreign investment in several African countries suggest an economic development "take-off". In recognition of this situation as well as the need to add value to the abundant natural resources, both governments and private entrepreneurs are investing in tertiary institutions in Africa focusing on Science, Technology, Engineering and Math (STEM) to provide the needed highly trained personnel to support and sustain economic development and growth. The core competencies and behaviors to be cultivated in these institutions are what STEM educators worldwide deem crucial for economic competitiveness and job creation. These include, according to the US National Academies Report, *The Engineer of 2020—Visions of Engineering in the New Century* (http://bit.ly/Y7qwK5): oral and written communications, critical thinking, analytical and innovative problem solving, practical ingenuity, creativity, agility, team work, and an appreciation for life-long learning. This presentation highlights the African University of Science and Technology (AUST), a private, pan-African, coeducational university located in Abuja, Nigeria. Its mission is to "advance knowledge and educate students in science, technology, and other areas of scholarship that will best serve the African continent in the 21st century". Starting in 2008, graduate programs at the master's level have been offered in Computer Science and Engineering, Materials Science and Engineering, Petroleum Engineering, Theoretical and Applied Physics, and Pure and Applied Mathematics. We discuss in particular opportunities for innovative ideas for the Material Science and Engineering curriculum. The desire is to ensure a well-rounded grounding of the students not only in the physical aspects of Materials Science but also the chemical aspects. A further intent is to inspire the students to ***make things*** by providing them with engineering tools and skills to apply their scientific knowledge of materials. We also discuss several challenges, including the backgrounds of the students, availability of faculty, the logistics of the number of courses, and the duration of each. In conclusion we contend that, despite severe challenges for tertiary institutions in Africa, it is important to make the most of opportunities to explore and adopt innovative curricula to achieve stated academic and national objectives.

Introduction

In the August 2012 issue of *Africa Renewal*, a publication by the Strategic Communications Division of the United Nations Department of Public Information, Kingsley Ighobor has an article[1] titled "African economies capture world attention". He highlights the strong economic transformation taking place on the continent in countries like Ghana with a remarkable 14.4 per cent growth of GDP in 2011. He cites a projection by the World Bank that in addition to Ghana, countries including Liberia, Nigeria, Ethiopia, and the Democratic Republic of the Congo will be among the world's economic growth leaders in 2012. Indeed the current transformation taking place on the continent is all the more remarkable when it is juxtaposed to the situation barely ten years ago. Ighobor recalls that in 2000, *The Economist* described Africa as "the hopeless continent," with headlines about bad governance, political conflicts, civil wars, famine, and the like. By December 2012 the same magazine wrote that now "the sun shines bright… the continent's impressive growth looks likely to continue." More recently *The Economist* carried a 14-page special report[2] titled "Emerging Africa" describing Africa as "the world's fastest-growing continent". Economies of African nations have attained the "take-off" stage of development.

It is an accepted norm that capacity building is required for sustained economic development. International and African organizations and governments espouse the need for accelerated capacity building, among many other measures, to ensure continued development and growth of African nations. The emphasis is on increased investments in education at tertiary institutions focusing on Science, Technology, Engineering and Mathematics (STEM) [3, 4]. STEM knowledge and skills are essential for innovation, with great direct benefits towards industrial development and manufacturing success[5]. Governments and private entrepreneurs recognize this and have invested and are continuing to invest in tertiary institutions in Africa that focus on STEM. The increases in student enrollments are substantial. Materu reports[6] tertiary student numbers grew by a factor of 3.6 between 1985 and 2002, averaging 15 per cent per year across the continent of Africa, and as high as 55 per cent in Rwanda. However, Materu bemoans the deterioration of quality that has accompanied the dramatic growth in numbers. No doubt greater numbers are needed, but we contend that relevance of the content of the curricula and heightened commitment to excellence by staff and students are more important. National University of Rwanda and Kigali Institute of Technology are remarkable examples of African tertiary institutions that have successfully achieved number growth as well as excellence in academic outcomes[7].

This paper highlights the experience of the African University of Science and Technology at Abuja (AUST-Abuja), a private, pan-African, coeducational university located in the federal capital of Nigeria. We do so because of our association as visiting professors there and our interest in ensuring relevance of curriculum and excellence to accompany numeric growth. AUST offers masters and PhD programs in five disciplines: Computer Science and Engineering, Pure and Applied Mathematics, Theoretical Physics, Petroleum Engineering, and Materials Science and Engineering (MSE).

Accelerated harvesting of Africa's wealth in mineral resources has undoubtedly contributed significantly to the impressive growth and transformation. Unfortunately the materials resources sector continues to be based on economic activities primarily focused on extraction and export of raw ores. Without a significant value addition to the abundant natural resources, the sector remains vulnerable to the swings in world commodity prices; and is incapable of benefiting from the much higher margins available for the variety of materials required by the rapid technological innovations taking place[8, 9].

How can Africans participate in and benefit from the materials technological boom? AUST-Abuja and its sister institutions described below have adopted as their mission to "advance knowledge and educate students in science, technology, and other areas of scholarship that will best serve the African continent in the 21st century". Our own association at AUST-Abuja with the Materials Science and Engineering department is the primary focus of our discussion.

Nelson Mandela Institution and Network of African Institutions of Science and Technology

AUST-Abuja is the first African Institute of Science and Technology (AIST) established by Nelson Mandela Institution (NMI). The idea for a network of tertiary institutions as centers of excellence in STEM education in Sub-Saharan Africa is the outcome of a conversation in early 2000 between Nelson Mandela and James Wolfensohn, then President of the World Bank. It gave birth to NMI whose vision was and continues to be "Knowledge Building and the Advancement of Science and Technology in Sub-Saharan Africa" via setting up a network of regional AISTs in West, East, South and Central Africa and supported as needed by regional centers of excellence. The intent is the "promotion of a Sub-Saharan African Learning Network to enhance broad-based knowledge creation, dissemination and flows across Sub-Saharan African countries through continuing education and the African Knowledge Forum". Ultimately the desire is that the outcome of excellence in science and engineering would be applied to "foster Sub-Saharan Africa's development and narrow the growing scientific and technological gaps between Sub-Saharan Africa and the rest of the world."

AUST-Abuja, the first AIST established by NMI in 2007, had 55 students admitted in 2008. It has to-date graduated nearly 200 MS students in the five disciplines: Computer Science and Engineering, Pure and Applied Mathematics, Theoretical Physics, Petroleum Engineering, and Materials Science and Engineering (MSE). Due to limited resources, instructors are visiting professors, mostly from the US, Europe, and Asia. Courses are short term in duration in contrast to the traditional semester or term schedules; they run for 2, 3 or 4 weeks, depending on the availability of the visiting professor. Each day consists of two class sessions of one and half hours each with, a thirty-minute break.

MSE at AUST: The AUST Materials Science and Engineering department received its first batch of 9 students in 2008. In 2009 one of the authors (KOA) was asked to coordinate the academic program. Below are some of the key considerations that informed the reassessment and modification of the curriculum.

- **Student backgrounds.** Few of the students had a first degree in Materials Science/Engineering. In the 2009 group, the undergraduate degrees were in Physics, Chemistry, and Minerals Engineering. In the case of the 2008 group the degrees were in Materials Science and Engineering, Mathematics and Statistics, and Physics. This raises the issue: Should we provide an introductory course in Materials Science and Engineering to adequately prepare them for graduate-level core courses? University of California, Berkeley has such a course: MSE 200A: Survey of Materials Science **http://www.mse.berkeley.edu/mse200a.php.**
- **Course level.** Several of the AUST visiting professors have found it difficult to teach their courses at the graduate level. Part of the problem is the heterogeneity of the student backgrounds, but a major contributor is the three-week timeframe for the courses. It is not likely that a longer time can be allotted in the foreseeable future, given the time commitments of visiting faculty at their home institutions and the limited financial resources at AUST for acquiring permanent faculty. Nonetheless, for the core courses to be useful as foundations for the Materials Program, they should be well assimilated by the students. A possible solution is to develop two-part core courses, e.g., Thermodynamics 1 and 2.
- **Context and pedagogy.** AUST is located in Africa. Should this make a difference in the Materials curriculum? One cannot seriously claim that there is an "African" Materials Science/Engineering. However, since this is an applied field, the context is an important factor[10]. Relevant considerations include the important role of minerals in the economies of many African nations, the abundance of sunlight, the need for low-cost infrastructural materials, the challenge of materials-related environmental pollution (e.g., plastic and electronic wastes).
- **Materials Chemistry vs. Materials Physics**. The field of Materials Science and Engineering is frequently viewed as comprising four key elements - processing, structure, property, and performance. The scientific underpinning relies on both chemistry and physics (and now increasingly also biology, mathematics, and computation). At the MS level the course work should provide a well-rounded grounding of the students in both the chemical and physical aspects of Materials Science. This will give them some flexibility when the time comes to select thesis research topics. Also, such a comprehensive foundation will make them more competitive as they seek to advance to the PhD level in world-class universities abroad.
- **Science vs. Engineering.** What is the proper balance between science and engineering in a Materials Science and Engineering curriculum? In the more industrialized countries this may be an irrelevant question; in the emerging era of nanotechnology the boundaries between science and engineering are increasingly blurring. Still, we do have engineering schools, which are apart from the schools of science. Engineers use science to make things for

society. Where do our AUST students see this happening around them? What George Essegbey wrote about Ghana[11] can be said about many other African countries:

> "Ghana makes science compulsory throughout secondary education, and an astonishing 46 per cent of students in Ghanaian universities and polytechnics are enrolled in science-related programmes. Yet all this activity has had little impact. There remains a huge gap between teaching and learning science and truly assimilating it so that it guides our thinking, decisions and actions."

More recently, in an article in one of the leading newspapers of Nigeria, *Vanguard*, Kalu lamented[12] that, "In Nigeria this quintessential continuum from basic to applied to developmental research is, as yet, practically nonexistent." He felt that "Among Nigeria's numerous and persistent problems, one of the most pressing is her backwardness in science and technology." He went on further:

"I subscribe to the view that if one is aware of the power of science and technology in promoting development, one is obligated to continue to implore the Nigerian government and the public to do what most of the advanced nations have done for centuries, and that is, to translate science into productive technologies and use the latter to fuel the development of their country."

How then can we inspire AUST students to ***make things***? The first step is to provide them with some engineering tools with which to use their scientific knowledge of materials. Engineering Design and Process Engineering skills (e.g. a course in Materials Process Engineering) may be useful in this connection.

Case Studies in Materials Processing

Case 1: Materials Processing course

Once each year, from 2008 to 2011 one of us (KOA) developed and offered a course in materials processing (MS 603) at AUST. A project report was one of the requirements. The 2009 project was entitled, *From Minerals to Materials: Adding Value to Our Solid Mineral Resources Through Aqueous Processing:*

> Your country's new Minister of Science and Technology just returned from an African Union Ministerial Forum on Science and Technology where she participated in a panel discussion on using Africa's natural resources base as a springboard for technological advancement. She was disturbed to learn of the manner in which African governments (including her own) have historically failed to come up with science and technology policies that seriously seek to add value to their countries' solid mineral resources. She also heard presentations that promoted the idea of "resource curse" as well as those that vehemently challenged this idea as in Sachs[13] and Wright[14].
>
> Upon her return from the forum, the Minister instructed the Director General (DG) of your country's Council for Scientific and Industrial Research (CSIR) to provide her with a comprehensive report on the state of the minerals and materials industry. In connection with this, your boss, the Director of the Center for Materials Research in Aqueous Systems (CMRAS) has asked you to contribute to an initial study to provide management with critical baseline data and assessment. Your work is to focus on aqueous-based chemical processing technologies.
>
> Prepare a report in response to this request. Your report should:
>
> (a) Identify two important (and different) solid mineral resources (deposits) in your country that are amenable to aqueous processing - either in the extraction or engineered materials synthesis and processing stages. Indicate the location and extent of these resources. What are

the important ore minerals associated with the deposits and what are the valuable metals therein?

(b) What are these metals and minerals used for? What are some commercial products which are based on the metals and/or minerals?

(c) Select one of the deposits. Describe the current nature and level of industrial activity (e.g., is the deposit being mined? Is there any mineral processing? Is there any hydrometallurgical processing? Are there known serious mining/processing environmental problems?

(d) What are the opportunities you see for adding further value to these resources? What specific contributions do you see for aqueous processing techniques (e.g., in connection with the metal extraction, engineered materials synthesis and processing stages, or environmental aspects).

(e) Select one of the "opportunities" identified in (d) above and describe, as quantitatively as possible, the relevant aqueous processing schemes.

(f) In view of your research findings pertaining to items (a) to (e) above, what is your reaction to the "resource curse" debate?

The technical content of your report should be based on the principles and tools discussed in MS 603. In particular, your report should demonstrate your familiarity with the following process chemistry tools: (i) Reaction quotients and equilibrium constants, (ii) aqueous stability diagrams, (iii) speciation diagrams, (iv) dissolution, precipitation, and selectivity windows, (v) reaction paths, and (vi) conceptual flow diagrams. The professional-quality report should not be more than 15 pages long (double-spaced) total. At least two-thirds of the report should focus on aqueous processing proper. You should take advantage of relevant information in textbooks, the patent literature, the internet, technical journals, conference proceedings, company brochures, and personal contacts (e.g., phone calls, e-mails). Be sure to consult more than one type of information source. Your report should clearly indicate some serious thinking on your part. At a mini-symposium at the end of the course each student will make a 20-minute presentation to report his/her findings. There will be peer review of the presentations. The relevant evaluation forms will be provided. Attire: Business casual.

This assignment was designed to encourage the students to appreciate the minerals-materials linkage, and to go beyond factual information to conceptual understanding and problem-solving. It was to challenge the students to reflect on and think broadly about their work as scientists and engineers. We wanted them to be aware of and appreciate the wider context and the policy implications of their science and engineering activities. It was also to nudge them towards viewing themselves as active participants in addressing Africa's science and technology challenges.

In tackling this assignment one of the major obstacles encountered by the students was the great pressure related to the limited time available. The instructor had decided that before embarking on the project the students should first be exposed to the process chemistry tools noted above. This meant the assignment was presented to the students in the last week of the 3-week course. One of the lessons learned is that it will be more productive to give this assignment on day 1 of the course. The general scientific and engineering competences acquired at the BS level, should have prepared them to start items a, b, and c in the assignment.

The students also struggled with the "this is not my field" syndrome. Parts a-c of the assignment required exploration of the geological and mineral engineering literatures. Aside from the anecdotal notion that Africa is richly endowed with natural resources, many students at this stage in their academic career have little knowledge about their countries' minerals resources and have no idea where and how to access such information. In the US we often tell our students that the challenge today is not lack of information, but how to use the ever-abundant information. For the AUST students, however, access to information was nontrivial. Library resources (physical plus online) were extremely limited, access to the computer lab was restricted, and the available bandwidth often made downloading a formidable task. In spite of the challenges above, the students' response to the course was positive overall, as captured in this remark from one of them: "We'll always cherish the experience. With such an assignment you brought many of us out of our shells and made us realize that 'nothing is impossible'."[15].

Case 2: Process engineering course

One of the changes proposed in 2010 to enhance the MSE curriculum was the addition of a course on Process Engineering. The second author (VAO), a chemical engineer, was asked to develop such a course for the 2011/2012 academic year. After a reasonable web-search of curricula at several universities around the world and consultations with colleagues, a decision was made to offer a course to introduce students to the strategy and methodology of process engineering. We sought to offer a course that would equip the students with the relevant thought processes, skills and approaches required to address process engineering challenges and opportunities. Specifically, the intent was to educate and train students to be able to define and develop the most effective commercial processes to address needs for materials for societal benefit and progress when a need is identified or a raw material is discovered.

We wanted them to dream and "Imagine that every material thing in your life suddenly disappears. Your car. Your home. Your clothes. Your jewelry. Everything, everything, is gone: the steel, concrete, glass, plastic, and thousands of other materials that made up your modern habitat are nowhere to be found in ready-to-use form. Naked in the wilderness, you are going to have to figure out how to transform the raw materials of the world into forms suitable for making [useful] things"[16]. The intent was to inspire students to focus on problem solving skills over mere acquisition of a body of knowledge on various classes of materials; and deliberately use open-ended inquiry-based pedagogy to stimulate critical thinking and develop creative skills and insights.

The course outline essentially followed the scope of process engineering which encompasses the items depicted in Figure 1[17]. The goal was to focus on the top four boxes and only briefly introduce the rest of the topics during the scheduled 15 days or 45 hours. Lectures consisted of presentation of key concepts as well as stories about notable people and their contributions to innovation in the technology of materials. The expectation was that the main learning of the students would be derived from tackling various carefully designed assignments with increasing complexity. Below is a selection of three such assignments:

1. Create 4 "family trees" linking 4 different "raw materials" to various "useful products". For example, consider coal and the many products derived from it, or how quartz is transformed into useful materials for various technologies.
2. Refer to slides about "Materials: The Stuff of History" (Figures 2 and 3) and write no more than a 5-page paper addressing the history of materials.
   - ✓ Provide support for the use and relative importance to society of the four classes of materials over the historical period shown.
   - ✓ Highlight several breakthrough material transformations that have influenced the course of history and industrial development.
   - ✓ Identify the key developers/innovators of the breakthrough transformations.
3. Kwame Nkrumah, Ghana's first Prime Minster had a post-independence desire for the development of an integrated aluminum industry in Ghana based on proven local bauxite ores. To address this desire he negotiated terms to build a 912 MW hydroelectric plant for the needed power to undergird this industrialization program. In the end what materialized

was the setting of up VALCO (Volta Aluminum Co.) to produce ultimately 200,000 tons per annum of aluminum ingots for downstream industries.

- ✓ Create a "family tree" involving aluminum (upstream & downstream) and highlight needs addressed by aluminium.
- ✓ Propose and assess at least 3 plausible process options to address the initial desire of the President. For each option highlight the challenges and opportunities.
- ✓ List and comment on Ghana government decisions since 2000 pertaining to this desire for an integrated aluminum industry.

The first offering of the course proved to be no easy task. As anticipated, students were very ill prepared for open-ended assignments. Several classroom sessions had to be devoted to brainstorming and idea generation activities to get them going on each assignment. Making matters worse, there were repeated power outages and thus students were unable to access web-based resources for information and ideas needed for timely execution of their assignments. Nearly all students revealed in the course evaluation that the brainstorming sessions were the most valuable of the class time.

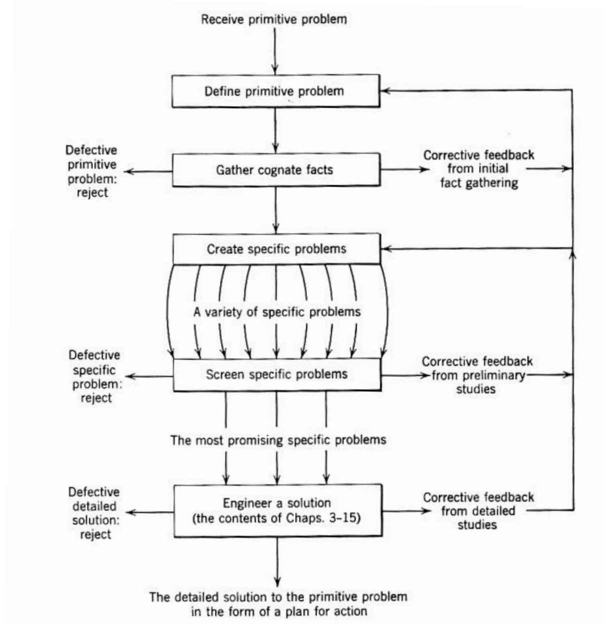

Figure 1: Process Engineering Challenge: Addressing "primitive" needs[17]

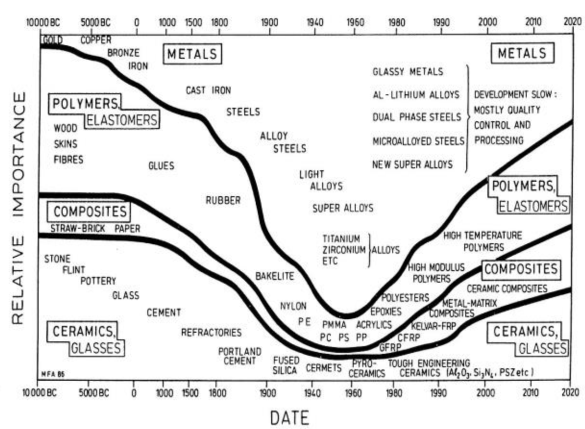

Figure 2: Materials: The Stuff of History[16]

Summary and conclusion

In this paper we have highlighted transformations taking place on the continent of Africa that augur well for her continued development. We have also contended that the needed growth in the numbers of graduates from tertiary institutions to support the development must of necessity be accompanied by excellence and relevance of the knowledge and skills they acquire. This in essence is what NMI is seeking to achieve through the network of regional AISTs in Africa. Our efforts in shaping the curriculum at the Materials Science and Engineering department of AUST-Abuja, the first of the AISTs, are an illustration of what is needed. Notwithstanding the inevitable challenges, the academic emphasis in all institutions must move from merely imbibing a body of scientific and technical knowledge to increasing skills and abilities to apply them to solving relevant problems of national interest.

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