

## **AC 2008-1455: WRITING A BOOK ON THE ROLE OF MATERIALS SCIENCE IN MANUFACTURING FOR INSTRUCTION AND RESEARCH: LESSONS LEARNED**

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# **Writing a Book on the Role of Materials Science in Manufacturing for Instruction and Research: Lessons Learned**

## **Abstract**

In 2006, the author and two colleagues published a materials science book that tried to integrate basic elements of processing science and manufacturing technology from a materials scientist's viewpoint. The book project essentially evolved as a scholarly experiment designed to 1) address opportunities and challenges faced over a decade of instructing students from diverse disciplines, and 2) create a cross-over instructional resource that emphasized the solid role of materials science in manufacturing for use chiefly by students of engineering studying manufacturing processes and materials science. The goal was to prepare an educational resource to supplement formal instruction that offered deeper, stand-alone coverage of selected processing topics than elementary textbooks that incorporate broader but shallower surveys arranged in an evolutionary pattern to establish the foundation of a class. The paper describes the author's own experiences in writing the book and addresses broader lessons learned.

## **Introduction**

The World Wide Web and public libraries are replete with wonderful resources on how to write a book. The abundance of accumulated wisdom of well-published authors enshrined in such resources undeniably is a valuable guide for beginners planning to tread an uncharted territory. This paper has a more modest goal: it describes the author's own first experience in writing a book on materials<sup>[1]</sup>. The paper does not provide metric or learning outcomes to assess the book's usefulness as a student resource; neither does it purport to promote and market the book in a community of scholars. The author's intent is simply to share the academic experiences and broader lessons learned in writing a book to aid the efforts of colleagues who envision undertaking similar scholarly endeavors for the first time.

## **Background and Motivation**

In his first formal teaching experience beginning in 1995 as a faculty member at the University of Wisconsin-Stout, the author encountered a recurring challenge in teaching materials courses concurrently to two distinct groups: one with students then in barely a year old B.S. degree program in manufacturing engineering, and the other with students from non-technical majors that, for the most part, also took many of the same classes. The widely different background knowledge and skills of students<sup>i</sup>, and their diverse career aspirations demanded an approach to teaching materials and processes courses that was relevant to both groups. Both groups needed to be exposed to content balanced between the applied and the theoretical (albeit with a greater

emphasis on vocational component, consistent with the university's historic strengths and applied character. The exigencies of program accreditation, a high university priority at that time, however, demanded integration of engineering science content to align the curriculum with the ABET standards).

The analytical content requiring math knowledge in such courses was adjusted to encourage participation and learning by the entire class. Additionally, our program's distinctly vocational focus required that the 'structure' component of the central paradigm of materials science: process → structure → properties → performance, be given reduced emphasis<sup>ii</sup>. This posed a challenge because understanding and visualizing how microstructure design via processing influences material behavior lays the foundation for understanding, analyzing, predicting and controlling the performance of larger, real systems. Likewise, mechanical behavior had to be explained qualitatively on the basis of continuum concepts but without invoking the atomic mechanisms which determine the macroscopic behavior and performance.

At this point, it may be instructive to revisit the general relationship of materials science to manufacturing. The essential foundation of manufacturing-intensive academic programs focused on applied materials and processes is shown in Fig. 1. The foundation is built upon the relationship among the '*structure and behavior of materials*' (*materials science*), the techniques of '*how to make things*' (*manufacturing technology*), and the '*theory of how things are made*' (*process engineering*). A number of materials and manufacturing books (Fig. 2) cover these aspects and some have actually helped lay the foundations of manufacturing engineering as an academic discipline. Both manufacturing engineering and materials science are relatively young academic disciplines that owe their origin to a number of intersecting fields. Materials science<sup>[2]</sup> underscores the underlying fundamental unity of diverse classes of materials at multiple length scales, and is closely aligned with manufacturing in its ultimate goals<sup>iii</sup>. As an academic discipline, manufacturing engineering emphasizes a 'generalist' approach and an application-oriented philosophy. A practical illustration could be that departments or units of a company are organized not as Heat & Mass Transfer Group, Computational Fluid Dynamics Group, and so forth but as Turbo-machinery Group, Sensor Technology Group, etc. The first grouping is conducive to discipline-specific 'knowledge-generation' function whereas the second grouping is appropriate for 'knowledge-application' function.

To teach materials and manufacturing courses to student populations possessing varying levels of skills and knowledge within a vocational-technical environment while striving to meet the accreditation criteria for engineering science made the identification and selection of suitable textbooks critical but also somewhat challenging. Whereas several excellent time-tested books including some listed in Fig. 2, adequately covered the content the students needed for the author's courses, none seemed to convey the spirit and the desired blending of science, engineering and technology components in the manner the author had envisioned. Many books were either 'science-heavy' or 'skill-intensive'. They were written either for students of material chemistry and material physics or for those training to become skilled crafts people. Some were designed to be comprehensive but elementary surveys that sacrificed technical depth. Vocational books paid little attention to engineering science content and science-intensive books excluded processing technology. In the author's opinion, the essential connectivity between materials science, process engineering, and manufacturing technology as envisioned by him was not

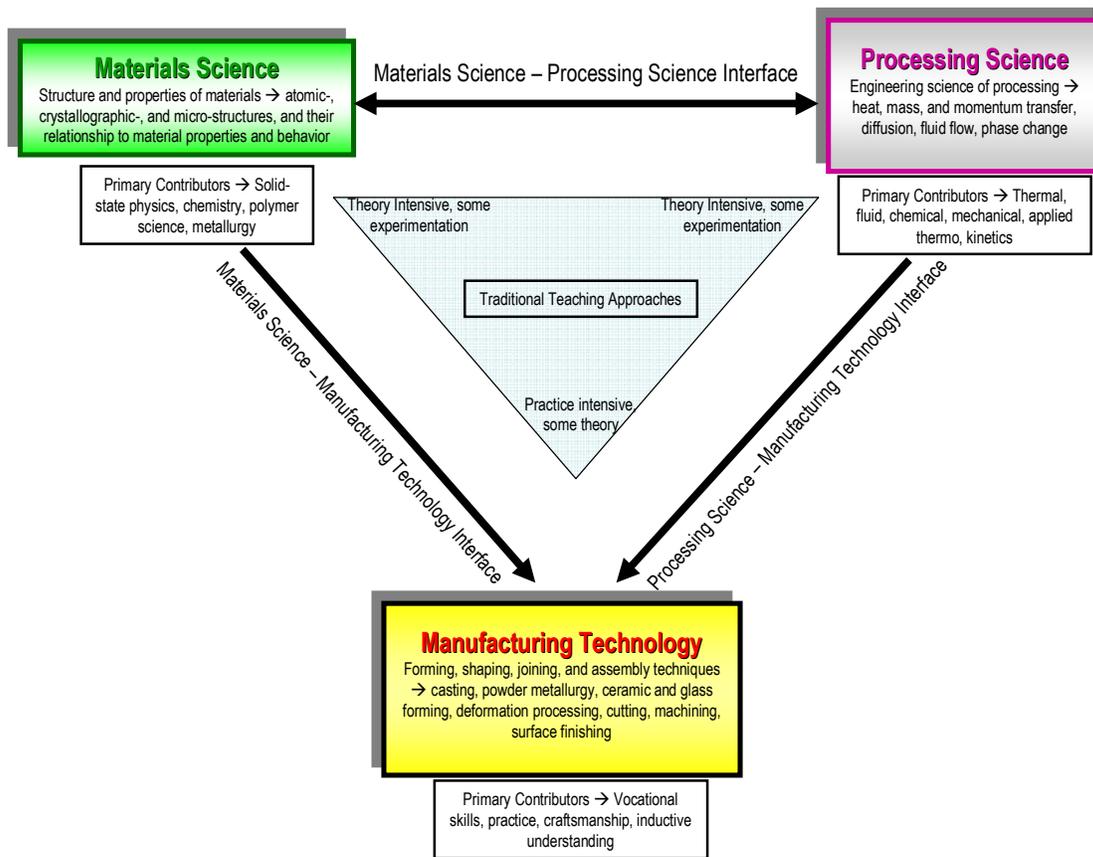


Figure 1. The triad of materials science, processing science and manufacturing technology.

brought out in these otherwise outstanding resources. It was felt that an integrative approach to teaching and learning and an associative instructional resource to accompany the standard textbooks were needed that not only obliterated conventional disciplinary boundaries but, more importantly, also helped cultivate a mind-set that facilitated voluntary transitioning between thinking like an engineer, a technologist, and a scientist. It may seem heretical, even a little daring to suggest this, especially because traditional college education cultivates and promotes ‘branding’<sup>iv</sup>. It is, however, envisioned that such a mind-set shall be compatible with an emerging manufacturing environment in which heretofore unfamiliar paradigms shall increasingly become commonplace and where tolerance for and acceptance of trends that are not contemporaneous<sup>v</sup> shall become compelling. There indeed is enhanced recognition in manufacturing circles of the critical role materials science plays in the design, synthesis, and fabrication of advanced materials at multiple length scales, particularly for materials for which the manufacturing technology is not mature. Materials phenomena are pervasive, cutting across disciplinary boundaries, and impacting diverse fields including but not limited to high-technology areas. Such phenomena often manifest themselves in ways that are difficult to capture and assimilate using paradigms specific to a single discipline.

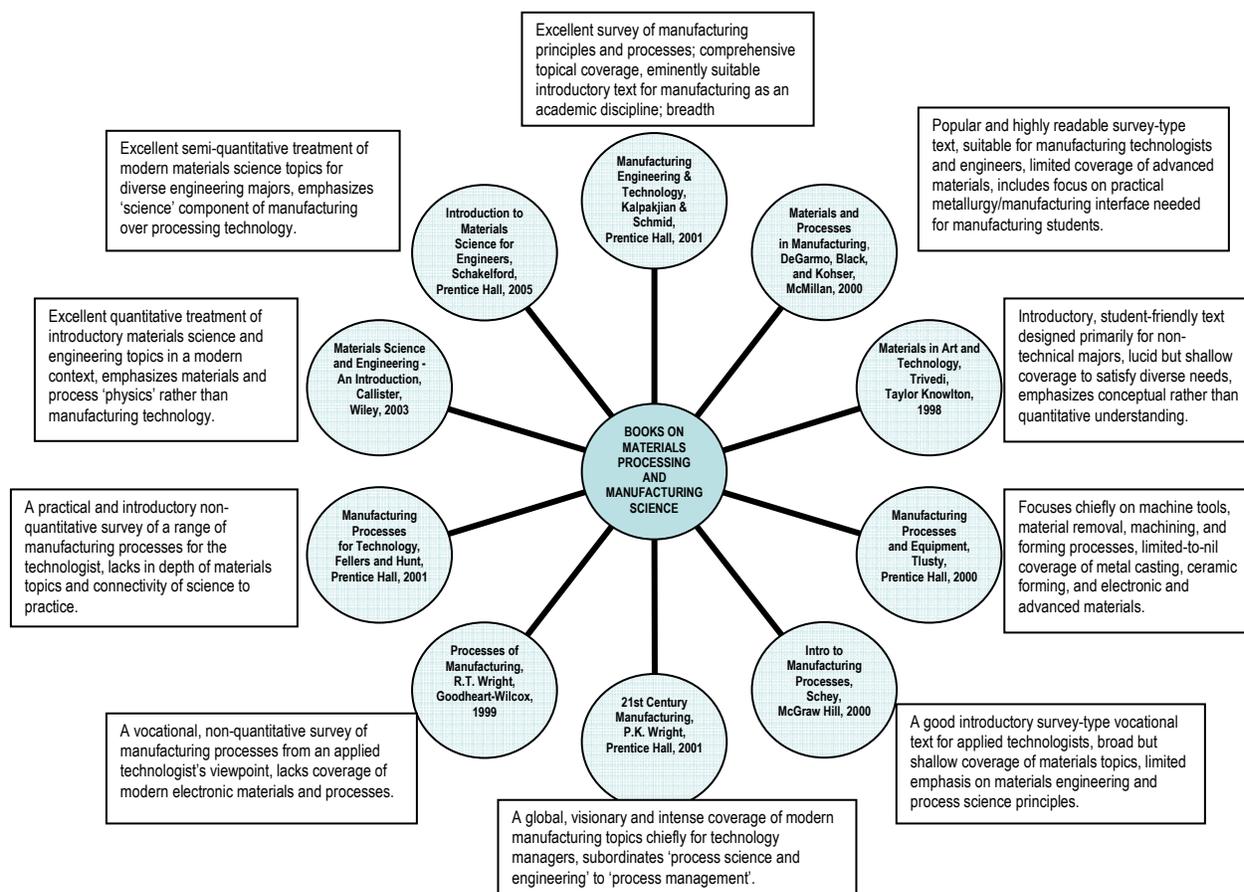


Fig. 2 A sampling of textbooks on materials and manufacturing related topics, and some of their special features, in the author's opinion.

In practical terms, all of this translated into a need for a resource that emphasized a fundamental understanding of manufacturing processes and their underlying commonalities, and blended the pure and the applied elements of diverse academic disciplines in an instructional resource<sup>vi</sup>. The importance of integrated teaching of science, technology and engineering in process-oriented courses can not be overemphasized<sup>vii</sup>. The author's book had its genesis in this premise and its writing was inspired by a number of courses<sup>viii</sup> that he had taught at UW-Stout since 1995. Additionally, the proposed book was to be based on the idea that progress in innovative and critical processing technologies demanded an understanding of the diversity and unity of approaches and methodologies across multiple disciplines and, that new pathways for knowledge generation and integration were likely to emerge from synergy among the current and evolving practices within diverse technical fields.

## Goals and Content

The book was organized into eight chapters, with each chapter focusing on a specific topic as displayed in Fig. 3, and spanning, on an average 75-80 printed pages. The book was designed to

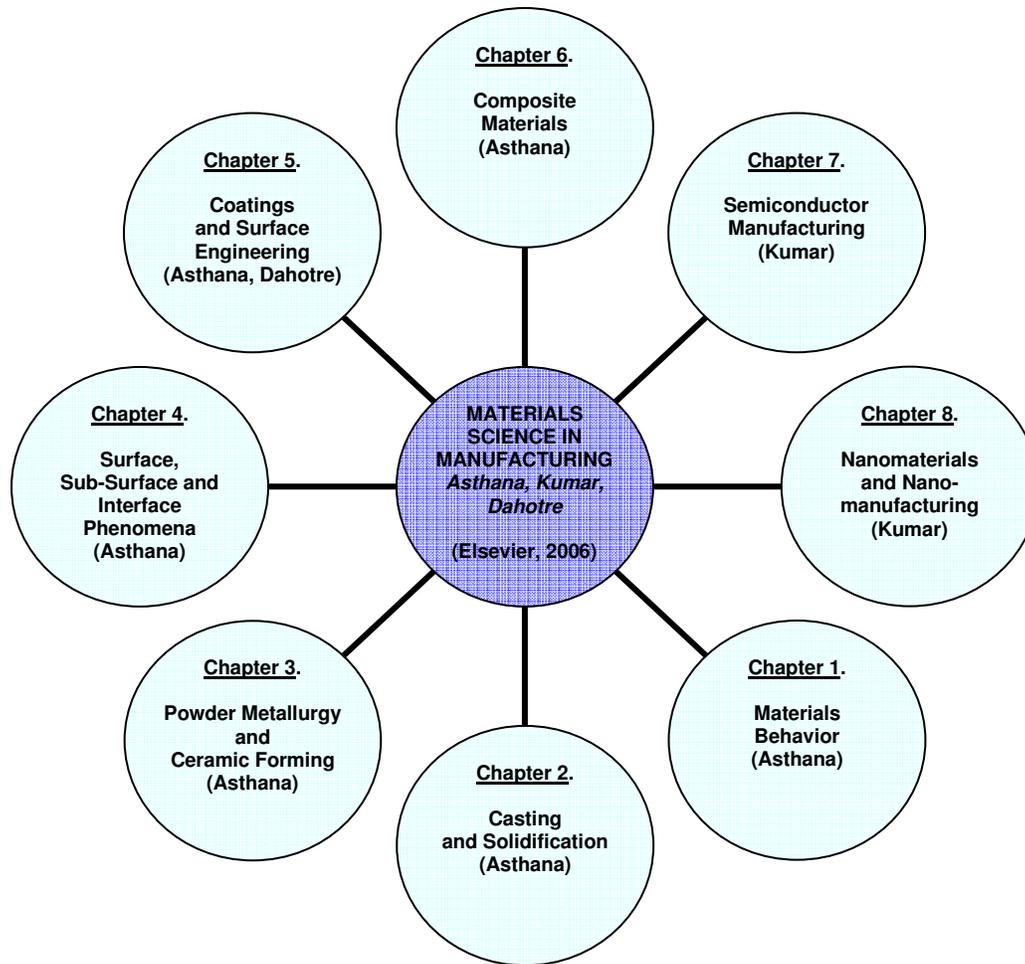


Fig. 3 Chapter organization and corresponding author responsible for each chapter.

provide a contextual background in the application of materials science and process engineering principles and theories to a variety of manufacturing technologies. It was assembled to cater to the needs of students who possessed basic, college-level background in physics, chemistry, and math through elementary calculus. The book was also to serve as a resource for those pursuing advanced graduate studies and research but possessing limited background knowledge in materials processing. It was, however, not meant to substitute a good undergraduate textbook, but rather serve as an essential accompaniment to it for in-depth and integrated treatment of selected materials processing topics. The book was not designed to develop the content in an evolutionary fashion that is normally needed to establish the foundation of an undergraduate course. It also did not include collections of solved examples and exercise problems; this was not something done on purpose or by design<sup>ix</sup> but because the authors simply ran out of time. This needed to be postponed for a future edition.

An example illustrating how the book attempted to blend the content related to manufacturing technology, process engineering, and materials science is shown in Fig. 4. For the topic of

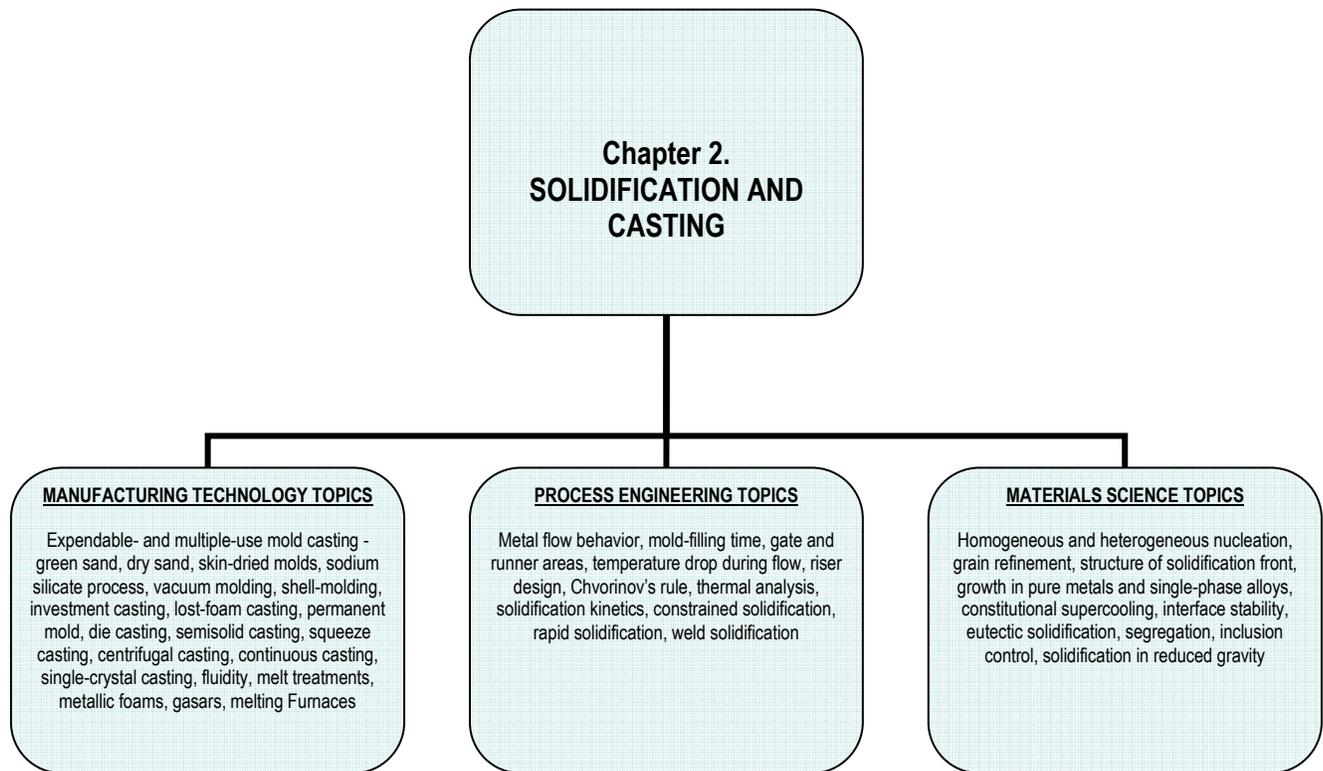


Fig. 4 Examples of the subtopics related to manufacturing technology, process engineering, and materials science included in the chapter, Solidification and Casting.

solidification and metal casting, the content based on the preceding three elements was organized roughly in the manner shown in this figure. Rigid compartmentalization was avoided to permit cross-over and blending between the three elements. Integration of the science of microstructure formation and tools and techniques of transport phenomena have elevated metal casting from predominantly skill-based profession to a scientific discipline that has assimilated the practitioner's art in a comprehensive technical framework and led to numerous innovations. The overall influence of such integration is difficult to capture as it has become pervasive and fundamental in altering our vision and thinking about solidification processing and metal casting. Chapter 2 of the book attempts to present an integrated understanding of the topic from the complementary viewpoints of the technologist, the engineer and the scientist.

A similar approach was followed for other processing topics such as powder metallurgy, sintering, metal injection molding, ceramic forming, coatings, surface engineering and a number of topics in other chapters. Integration of the content was achieved by closely following the top-down approach akin to reverse engineering, and by concurrently analyzing each manufacturing process from diverse but complementary perspectives of the scientist, the technologist, and the engineer.

The decision to cover both traditional and emerging materials and processes, depicted in Fig. 3, including a full-length chapter on nanomaterials and nanomanufacturing was motivated by the realization that the pace of development of advanced materials and their applications has been accelerating, and that novel experimental materials graduate at increasing pace from sheer lab curiosity to become a part of everyday life<sup>x</sup>. However, inclusion of newer topics that were scantily covered in standard textbooks and a focus on an in-depth treatment of a number of areas inevitably displaced some other, equally important, content such as metal working and polymer processing<sup>xi</sup>. This was considered acceptable, although not desirable, in view of the availability of a number of excellent resources covering these latter topics.

Although the book primarily evolved out of lectures given over a decade or more by each author on one or more topics covered in the book, some content derived directly from scholarly writing for the professional community and from the authors' own research activities. All three authors had originally trained as metallurgical engineers, but their subsequent education and training, and professional interests over the last 20 years diversified to cover different areas that dictated the topics (and corresponding chapters in the book) each was responsible for. Whereas infusion of research and scholarly writing into some of the content enabled the authors to strengthen the content, it also detracted from the uniformity and consistency in writing style and content delivery to the extent desired. For example, Ch. 7 (Semiconductor Manufacturing) is presented chiefly in a definitional (bullet) form, Ch. 8 (Nanomaterials and Nanomanufacturing) in a technical review form (partly mandated due to the evolving, dynamic nature of the topic), and the remaining chapters (Ch. 1 through 6) in a more traditional narrative/explanatory/semi-quantitative format. Such variations in content delivery and readability shall probably not deter the advanced student; however, they could render comprehension of the content somewhat difficult for the beginning student who may have to struggle with a new subject matter while grappling with a constantly varying style of content delivery. Proper resolution of this shall have to await a future edition.

Overall, the book's scholarly strength as well as its vulnerability to potential censure stem from a number of factors. First, the authors' effort to understand and describe manufacturing processes principally from the vantage point of materials science contrasts with the 'generalist' approach followed in many books that focus chiefly on broader manufacturing issues while narrowly and scantily integrating the elements of MSE and process engineering. Second, exclusion of some important topics (polymers and metal working) and occasional inconsistency in writing style and content delivery could be potential weaknesses from a pedagogical viewpoint. On balance, however, in spite of such shortcomings, the book was felt to be a useful resource for an in-depth discussion and analysis of selected processing topics, and for demonstrating the interrelationship among materials science, processing science and manufacturing technology for a variety of traditional and emerging materials and processes. The book is currently used as a reference for the senior level undergraduate courses MSE-390: Principles of Metallic Materials at the University of Tennessee-Knoxville, and MFGE-352: Manufacturing Process Engineering II at the University of Wisconsin-Stout. It is also proposed to use the book as a resource for the course MFGE-771: Emerging Manufacturing Materials, currently being developed for the M.S. in manufacturing engineering program at UW-Stout.

## Lessons Learned and General Remarks

Book writing essentially is a warehousing function in the knowledge generation and dissemination industry. However, besides archiving disciplinary knowledge, a book must also educate and inspire, especially if it aims to influence the reader's vision. In this context, ultimately, the question that technical book writers must ask themselves before developing roadmaps and milestones is this: is the book primarily designed to cater to the foundational needs of those who, in the long run, would train to participate in the knowledge generation and dissemination functions of a discipline or will it serve those who would master state-of-the-art geared toward application to outside realm? Whereas a clear and definitive answer to this question is seldom possible and rarely desirable, and it will inevitably be colored by the authors' own vision, it is nevertheless important to consider it in order to develop focus and direction.

To ensure currency of information, a thorough treatment of topics, comprehensive and authoritative coverage, and elimination of possible errors of fact, data or judgment, it is a good practice to solicit unbiased and constructive criticism from knowledgeable practitioners, authors, and potential users from industry, government and academia. This should preferably precede the manuscript review process initiated and organized by the publisher. Additionally, a considerable amount of time and effort is needed to complete the 'boiler-plate' stuff. Securing copyright permissions, preparing index, front matter, and proof reading and correcting multiple drafts are all important and time-consuming tasks and essentially the authors' responsibility even when help is made available by the publishers.

To achieve consistency in writing, coherency in vision, and unity in ideas that are often lost in assemblages of discrete, multi-authored works, continuous exchange of information, ideas, and written drafts among the authors is imperative. This may at times be difficult because of other demanding professional obligations that vie for immediate and unceasing attention, but should nevertheless be strived for.

A simple but important lesson in technical book writing concerns the pace of writing. Perhaps a little unlike works of creative fiction, technical book writing demands considerable attention to detail and workmanship, which, in turn, demand a slow and steady pace of writing for best results. A slow and steady pace also permits creative insights, connections, examples and solutions to emerge that would not normally arise under duress. The danger, however, of a slow pace of writing is a gradual loss of momentum and eventual shelving of the project abetted by mounting pressures of numerous other professional obligations. A fine balance is the key. Published data and personal testimonies reveal that a large percentage of technical book writing projects never get completed. In the author's case, a relatively clear conception of external needs and an understanding of internal motivators colluded to permit completion of this unfunded, free-lance project with two colleagues over a four year period while teaching a full load of 12 credits per semester, and maintaining active involvement in an assortment of research, scholarly and professional service activities<sup>xii</sup>.

Each book represents considerable investment of time and effort and is like bringing a child into this world. It is, therefore, essential to develop some understanding of why someone would want to invest time and effort to write a book. External factors such as those engendered by a unique

or pressing academic need for scantily available instructional resources such as those alluded to under ‘Motivation and Background’ usually outweigh private reasons which nonetheless may also play a role. In the author’s case, in particular, a disconnection with the generative, archiving and dissemination activities in the field in which he had trained and been involved with for over a decade prior to entering academe was perceived as a potential threat leading to a gradual erosion of professional identity. Book writing suited the author’s disposition and served as a platform to establish rapprochement between the external needs and internal compulsions. The danger in all of this, however, is that the effort may degenerate into a gratuitous activity and not serve any real purpose.

Ultimately, conceiving, developing, interrogating and completing a full-length book as scholarly output of free-lance academic work was quite demanding, but timely and successful completion of the project proved to be infinitely satisfying. It is the earnest hope of the author that the book shall meet the goals it was designed for.

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<sup>i</sup>Surprisingly, student evaluations often showed that the academic performance of a minority of motivated non-technical students in a class was comparable to if not better than that of some of the best technical students!

<sup>ii</sup> The program and curriculum evolution in engineering and technology areas over the last decade at UW-Stout has facilitated inclusion of the ‘structure’ component in appropriate courses.

<sup>iii</sup>Frank Press, former President of National Academy of Sciences<sup>[3]</sup>: *‘MSE has deep intellectual roots, which promise deep contributions to nation’s prosperity, security, and quality of life. It intimately combines knowledge of the condensed state of matter with real world of function and performance. It links the quest for deep and fundamental understanding of matter with the imperative of satisfying man’s needs. Overall, MSE is....coupled with... requirements for products, structures, machines and devices.’*

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<sup>iv</sup>During a conversation some years ago, a colleague from science stream asked the author if he had trained as an engineer or a scientist! With degrees in ‘materials science & engineering (MSE)’, the author (and others like him) could pass as either. We talk of mechanical engineering, electrical engineering, and civil (no pun intended!) engineering rather than mechanical science & engineering, electrical science & engineering and so forth (an exception besides MSE is computer science & engineering).

<sup>v</sup>A case in point is the development of ceramic and metal composites. In his Foreword to the author’s book<sup>[4]</sup> on composites, James R. Johnson, a former president of the American Ceramic Society, wrote in 1996: *‘It is interesting to look back more than fifty years at the status then of composites in the metals and ceramics fields. Among some scientists and engineers, particularly in the aircraft programs, there was a lot of excitement about their prospects. At the same time, there were detractors who believed that rather than achieving wonderful new engineered materials the composite pioneers would merely combine the worst properties of each material in the final product....’*

<sup>vi</sup>The intimate blending of the ‘pure’ and the ‘applied’ in pursuit of a shared vision is revealed in the following comments by two materials leaders, Ashby<sup>[5]</sup> and Flemings<sup>[6]</sup>. Whereas Ashby feels that an overemphasis on science in MSE has been detrimental to the practitioner’s cause, Flemings feels that science has actually aided growth of applied disciplines. According to Ashby, *“...the subject of materials is a broad one, drawing together understanding from physics, from chemistry, from mathematics.....The teaching of materials today is still colored by its more recent history, in which the physicist played a great part. The starting point...leads on to concepts of atomic bonding, to the geometry of molecular and crystal structures...to alloy theory and so on.....This understanding is the foundation on which the subject rests...But it is a path that creates a difficulty: the information the engineer really needs...comes only at the end or not at all.”* In analyzing the decline in MSE enrollment, Flemings highlights how chemical engineering, facing a similar decline, turned around the dwindling enrollments through an emphasis on science: *“How has chemical engineering achieved this turnaround?..... Importantly, the practitioners of chemical engineering.... were also clear as to the engineering science, the central paradigm that underlies their field. It is thermodynamics, transport properties, and reaction kinetics.... With eminent success, they have turned from oil refining and bulk processing to apply their basic tools to areas where they can have a greater economic and societal impact.”* Each approaches the field from a different side and presents a holistic vision of the discipline by advocating inclusion of complementary strengths.

<sup>vii</sup>In the past, concerns have been raised about a lack of integration in technical curricula. A National Academies Report<sup>[7]</sup> stated, *“...The area of synthesis and processing has suffered neglect in our universities and industry. A particularly compelling need is to provide undergraduates with a thorough grounding in the science and engineering of processing and its relation to manufacturing...New courses and textbooks are needed at both the undergraduate and graduate levels ...These textbooks should also explicitly address the complementary approaches of physics, chemistry and engineering.”*

<sup>viii</sup>These courses included MFGT-253 Joining and Casting, MFGE-343 Casting, Ceramics & Powder Metal Processes, MFGT-150 Intro to Engineering Materials, MFGE-383 Coating,

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Finishing & Packaging, MFGE-352 Manufacturing Process Engineering II, and MFGT-315 Metallurgy.

<sup>ix</sup>The authors were well aware of the immense benefits of hands-on learning, and had actually started to put together exercise problems and solved examples.

<sup>x</sup>A now commonplace material, steel, undeniably was an ‘advanced’ material in early 20<sup>th</sup> century and major developments in steelmaking were considered breakthroughs. An early steel pioneer, Henry Marion Howe, was presented with the engineering profession’s highest honor, the John Fritz medal, in 1917 after such luminaries as Thomas Edison, George Westinghouse, Alexander Graham Bell, and Alfred Noble.

<sup>xi</sup>There is some discussion of polymers and their processing and properties in Chapter 6: Composite Materials. But the coverage is brief (about 10 book pages) and, therefore, incompatible with the technological importance of polymers.

<sup>xii</sup>A supportive and understanding family is usually a most potent but little acknowledged force in facilitating completion of scholarly works.