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TRIBUTE

General Commentary: A Tribute to Professor Kenneth R. Morris – Scientist, Teacher, Mentor, Friend…and Underappreciated Academic Arborist

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Introduction

This special issue of *Pharmaceutical Research* is dedicated to Professor Kenneth R. Morris, who for more than 3 decades has been a leader in research devoted to the interplay between pharmaceutical materials science and advanced manufacturing. Given that, it was relatively straightforward for the Guest Co-Editors to settle on the theme of this issue: *Improving Product Quality through Process and Materials Understanding*.

I started writing this commentary several times before I finally settled on an idea, which came from a picture taken at the 2019 AAPS *PharmSci360* Meeting in San Antonio, TX (Fig. 1). At that meeting, my own graduate student, Mustafa Bookwala (PhD 2023) was presenting his poster and Ken, Sam Yalkowsky (Ken's PhD advisor), and Dave Engers (my former Morris Group lab-mate and one of the Guest Co-Editors of this special issue), all showed up to hear the presentation and to ask questions. We recognized the rarity of having four generations from the same academic family in one place at one time, and decided to commemorate the moment.

Over the years, I had become the unofficial keeper of the Yalkowsky academic family tree, which was last updated in 2018 for the *Special Issue* of *Journal of Pharmaceutical Sciences* dedicated to Sam [1]. For as long as I've known him, Ken has often referred to this tree – always making a point of introducing me to its members, who are my academic siblings, cousins, great-aunts and uncles, and great- and great-great-grandparents. Thinking of this, I decided that as a tribute to Ken, I would try and tell the story of his academic family tree, which from a cutting of my branch, I have begun to grow my own. I used the phrase "*underappreciated academic arborist*" in the title of this tribute, because, it took writing this commentary, and collecting reflections from Ken's past graduate students, for me to realize how purposeful Ken has been in the cultivation of his tree throughout the years.

The roots of Ken's tree grow from Professor George Zografi at the *University of Wisconsin-Madison* through Professor Sam Yalkowsky at the *University of Arizona*, forming a trunk resplendent with the many branches of Ken's academic career. I would be remiss, however, if I failed to acknowledge the tremendously diverse elements of his pre-academia life, because one of the favorite pastimes of students in the Morris Group was trying to keep track of all of the jobs that Ken had had in his life. As he told it, Ken was a janitor at *Eastern Michigan University*. Ken was a rock star – or, at least Fig. 2 exists as proof that he recorded an album with his band, that someday I hope to hear.

He worked for the *U.S. Fish and Wildlife Service* on a boat on the Great Lakes, and upon learning of my love of Gordon Lightfoot's music, told me a story of having used sonar to view the wreck of the *Edmund Fitzgerald*. He then worked at the *Environmental Protection Agency* where he met Sam Yalkowsky. Somewhere in that history, Ken was also a dog groomer in San Francisco, whose clients actually included Janis Joplin (who he narrowly missed). Group meetings always seemed to include a new story of what Ken had done in the years before we knew him. In retrospect, it's clear now how his love of art and music merged with his approach to science, and combined with a multitude of experiences that fueled his desire to pursue so many different avenues of understanding pharmaceutical materials by studying molecular mechanisms. This has given so much shape to the sprout that grew from the Yalkowsky academic tree in 1987, when Ken earned his PhD from the *University of Arizona* [2, 3].

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Fig. 1 Picture taken at 2019 AAPS *PharmSci360* (San Antonio, TX). From left to right: Mustafa Bookwala, Peter Wildfong, Ken Morris, Sam Yalkowsky, and David Engers.

Fig. 2 I have never managed to hear Ken's legendary band (left). I hope that someone, somewhere, has a recording of *Kodai Road*. Fortunately, Ken continues to play music – maybe a bootleg recording of him at this Dog Park concert (right) exists on one of the streaming services

Research from E.R. Squibb & Sons and Rutgers University (1987–1996)

Following his PhD, Ken joined the development team at *E.R. Squibb & Sons*, where he began pursuing numerous fundamental questions in pharmaceutical materials and processing [4–6]. At the same time, Ken's own academic tree sprouted its first branches at *Rutgers University* with the advisement of 2 PhD students and an additional MS thesis. His use of dielectric analysis to predict lyophile collapse temperature [7, 8] and characterization of film curing [9] point towards Ken's lifelong goal of understanding more fully the fundamental underpinnings of key materials phenomena as they relate to drug products.

Research from Purdue University (1996–2008)

In 1996, Ken joined the *Department of Industrial and Physical Pharmacy* at *Purdue University*, and just prior to my joining the story, graduated his first MS student, whose work

on online NIR measurements of powder blending helped begin the Process Analytical Technology (PAT) revolution in the pharmaceutical industry [10]. Around that same time, I was exploring the possibilities of graduate school in pharmaceutics, and had a phone meeting with Professor Nair Rodriguez (*University of Michigan*), who as Ken's co-advisor, was another branch from the Zografi-Yalkowksy-Morris tree that I didn't know about at the time. She encouraged me to think about applying to *Purdue*, and Ken's group in particular. That recommendation proved critical to my own scientific career path, and I joined the Morris Group in June 2000.

During my first week of graduate school, I met with Ken to discuss what the focus of my dissertation project would be. Figure 3 captures Ken, as all of the *Purdue* Morris Group alumni first met him – in his dark dungeon of an office, tucked back into a not-easily-accessed corner of a hallway, in the basement of the *Robert E. Heine Pharmacy Building*. I'm fairly certain that the office was a repurposed storage closet, whose walls were lined with books—a tiny fraction of Ken's legendary personal library at home. Ken's feet were propped up on casing that covered some electrical wiring too unsightly to display on the walls where the PharmD students might see them. A single navy-blue tie hung from a hook on the back of his door. When I asked him about it, he answered, "*I wear that when I have to go and ask for funding*." True to his word, I only ever saw Ken wear this tie when pitching projects to the various groups that he had helped establish, including the *Consortium for the Advancement of Manufacturing Pharmaceuticals* (C.A.M.P.), the *Purdue-Wisconsin Program for Study of Chemical and Physical Stability of Pharmaceuticals*, and the *NSF Center for Pharmaceutical Processing Research* (C.P.P.R.). Ken utilized these consortia to expose his students to the importance of collaborations within the pharmaceutical sciences. In fact, Ken's mission at conferences, symposia, and meetings of this sort were to advocate for his graduate students, to make sure that we were all aligned with jobs when we graduated. As recalled by Morris Group alumnus Dr. Abhay Gupta (PhD, 2004): "[*Ken*] *used to take me to C.A.M.P. Meetings to present my work in front of senior leaders – I now call those presentations simultaneously giving me multiple job interviews.*" Beyond exposing his students to their future employers though, Ken "*taught us how to seek out collaborations with other departments and other companies. These skills have helped me grow throughout my whole career. I learned so much from him, and never thanked him enough for sharing his knowledge. My learnings and experiences with Dr. Morris were priceless*," (Dr. Jose Pérez-Ramos, PhD, 2007).

In my early conversations with Ken, I remember three distinct things. The first was that Ken divided research into "*Projects that pay the bills and projects that you dig into for fun.*" Instead of just assigning me a topic, Ken encouraged me to find a dissertation project that accomplished both [11]. The second thing I remember is that Ken had a near encyclopedic knowledge of every curse-word known to humanity, and could weave them into even the most technical scientific discussion. In fact, when I'm paraphrasing Ken's wisdom to my own graduate students, I have to make sure that my brain operates on enough of a delay that I don't accidentally curse like a pirate while trying to make my point. The third thing I remember about conversations with Ken, is that he always made time to have them, regardless of how busy he was. As Dr. Tiffani (Davis) Eisenhauer (PhD, 2002) recalled: "*Occasionally, I needed to talk with Ken about something, but he was on his way to another lab or to a meeting. Instead of asking me to come back later, he would always say, 'Walk with me,' and we would discuss my question as we walked. During my career I have often done the same, and I always think back to Ken.*" What Tiff left out of that memory was the number of times she was left stranded in the hallway,

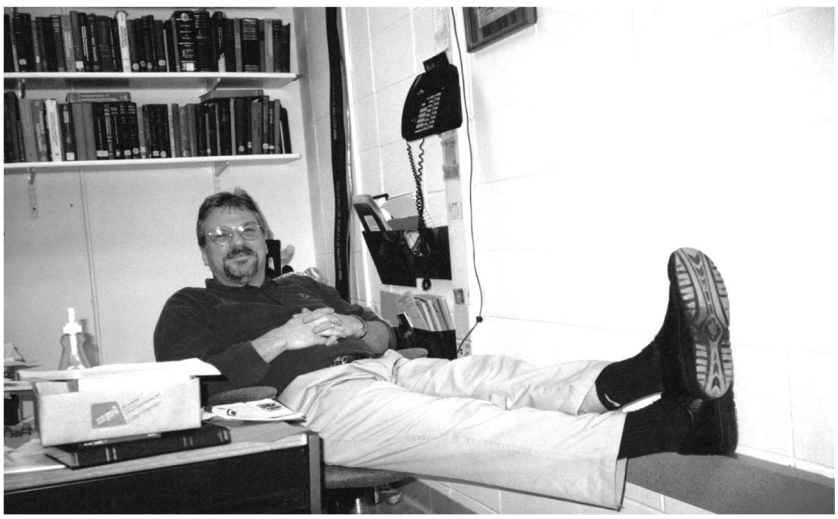

Fig. 3 Professor Ken Morris, in his office at *Purdue University* (ca. 2000). Not pictured: the navy-blue tie hanging on the back of Ken's office door (Ken confirmed that he owns it to this day, and still wears it, albeit rarely)

outside the door to the men's bathroom because Ken had walked in (mid-sentence) during their conversation. As a junior student at the time, I was often asked to stand inside the bathroom door so that I could fill in the gap of those conversations for which she was unable to accompany him.

Despite diverse interests, Ken remained focused on his purpose to improve the quality of drug products by rigorous understanding of the materials from which they're comprised, and the processes used to manufacture them. Ken always had a new idea taken from an article he had just read, or found in a passage from one of the physics or chemistry books in his home library. As remembered by Morris Group alumnus Dr. Paul Findlay (PhD, 2003): "*Ken would send emails with ideas, thoughts, and things to do at crazy early hours of the morning. It got to the point that, for at least a semester or two, I adjusted my schedule, getting up at about 4 AM every day, just so I could respond to the emails right away (or at least by the time I got into the lab later in the morning).*" While the canopy of Ken's tree began expanding in New Jersey, it was at *Purdue* where it grew to its fullest breadth:

- Developing models of tablet punch face adhesion [12–14] and mechanisms of eutectic formation during tablet compaction [15, 16]
- The use of master curves to predict relaxation behavior of amorphous materials [17–19], the influence of microstructural evolution on amorphous phase instability [20], and directed polymorphic growth using capillary precipitation [21]
- The use of parallel-beam PXRD to allow *in situ* monitoring of processed-induced phase transformations during wet granulation [22–24] and quantitation of compaction-induced polymorphism [25–28]
- The use of NIR spectroscopy to determine the end point of fluidized bed granulation [29, 30]; accelerated fluidized bed drying of low melting temperature compounds [31, 32]; studying the influence of ambient moisture on the compaction behavior of MCC during roller-compaction [33–37]; and real-time quantitative analyses of film-coatings with NIR spectroscopy during pan coating [38–41]
- Predictions of crystal-to-crystal [42] and crystal-to-amorphous [43] phase transformations induced by high-shear mechanical processing
- Using dielectric properties of pharmaceutically relevant mixtures to understand triboelectric charging during tumble blending [44, 45]
- Computational methods for core–shell potential-derived point charges [46–48]
- Assessing drug dissolution from pregelatinized corn starch capsules [49, 50] and the contribution of secondary relaxation processes in acrylate polymers to permeate diffusion [51, 52]

Integrating these diverse topics was the purview of our weekly group meetings. In addition to regaling us with the aforementioned stories from his past and expanding our respective curse-word vocabularies, these were opportunities for us to better understand the questions that we were asking. As recalled by Dr. Jose Pérez-Ramos (PhD, 2007), "*Ken taught us how to think…* [He was] *always challenging us to stretch our understanding on chemistry, physics, and advanced materials sciences to the maximum. For every model, he would ask us to derive the equations and to explain the assumptions. For every experiment, he would ask us to provide a hypothesis, identify the variables, and to predict the outcomes.*" Importantly, however, Ken didn't just ask us to select from the menu of topics in which he was interested. He empowered us to dig deeply into projects that interested *us*, while taking care of the funding needed to keep those projects moving forward. Morris Group alumnus Dr. Jeff Tan (PhD, 2007) remembers that "*Ken created opportunities…He recognized the need for me to be exposed to the lab and created an internship opportunity for me to do so in an industrial setting. Through both of these, Ken played a key role in shaping my passion for computational/experimental approaches that continues to drive what I do today.*" The diversity of research areas at these group meetings was so important to all of our growths as scientists. We not only got to learn about research on topics outside our immediate areas of focus, we strove to understand the work that one another was doing.

As I approached my defense and graduation in 2004, Ken and I returned to conversations about our mutual academic family tree. He had recognized my own passion for research and teaching, having given me the opportunity to revise a portion of the manufacturing lab course at *Purdue*. I don't remember who had pointed out to Ken that academic careers should beget new academic careers, but I clearly remember Ken's encouragement and support as I applied for a faculty position in Pharmaceutical Sciences at *Duquesne University*. To say that Ken was instrumental in planting my own sapling in Pittsburgh would be an understatement. Reflecting today on his continuous support and encouragement was how I thought of the phrase "academic arborist" for the title.

Research from University of Hawaii-Hilo (2008–2015)

In 2008, Ken left Purdue to help establish a new *College of Pharmacy* at the *University of Hawaii*. The demands of this new and growing school didn't stop Ken from pursuing his research passions, and he established a new lab in Hilo. Collaborating with post-doctoral fellow Dr. Rahul Haware (also a Guest Co-Editor of this special issue), Ken continued contributing to his ever-growing work in process-induced phase transformations of pharmaceutical materials [53].

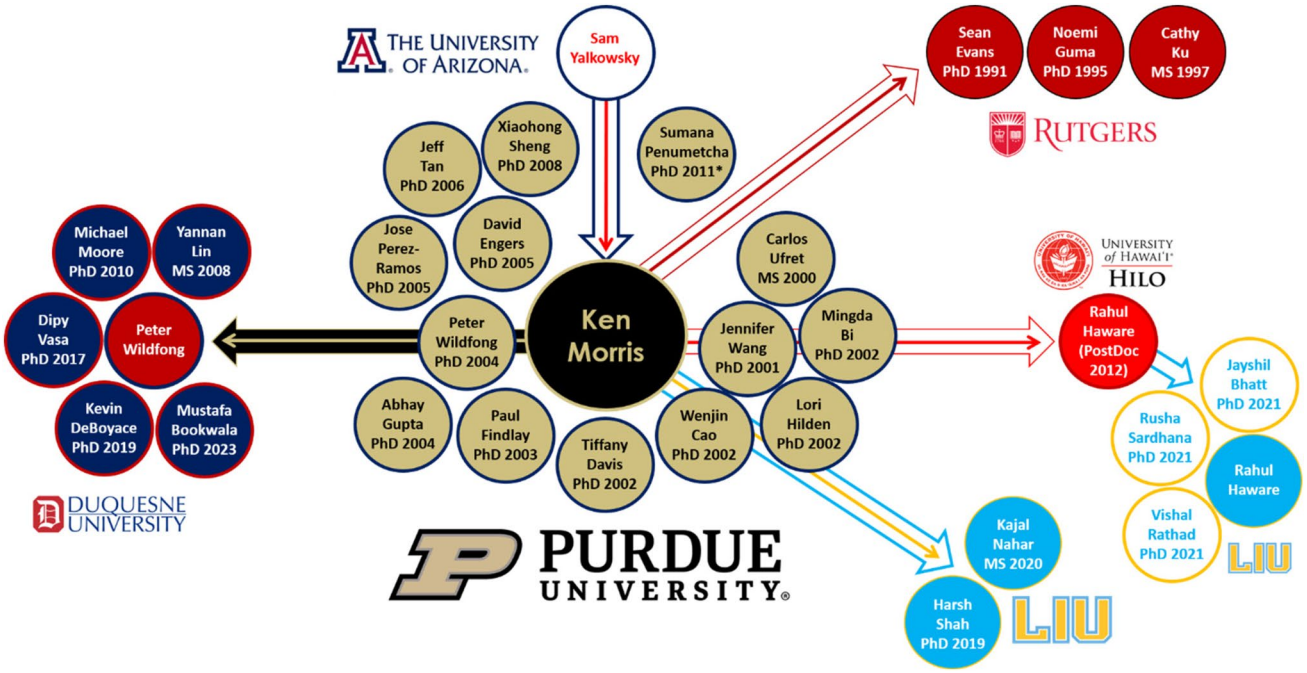

Fig. 4 The Morris Academic Family Tree, as of November 4, 2023

Research from Long Island University (2015–2021)

Ken moved from the *University of Hawaii* back to the mainland in 2015, and started a new lab at *Long Island University* in Brooklyn, NY. As with every other stage of his career, Ken furthered existing collaborations and began new ones, ever adding to the branches of his tree. He worked closely with the FDA, again pursuing fundamental questions related to pharmaceutical materials in conjunction with improving regulatory science [54]. He contributed to numerous pharmaceutics projects at *LIU* [55–64], and his last two graduate students continued working to gather more materials understanding, through classification of solid-state properties for narrow therapeutic index drug substances [54, 65–68] and estimating intrinsic solubility and intrinsic dissolution rate of the metastable form of a drug [59, 61, 64, 69, 70]. Ken also helped plant a new tree when Dr. Rahul Haware followed him from Hilo to Brooklyn to start his own lab.

Concluding Thoughts on a Prolific Career

When Ken called to tell me that he and Maggie, his wife and partner of 50 years, were retiring, I think I laughed out loud – not out of any disrespect, rather from surprise and a sense disbelief. It was hard to picture Ken being "retired." I had known of Ken Morris the scientist and of his work before I applied to join his lab at Purdue. After all, when I started learning about the intersection of pharmaceutics and materials science, his was one of the first names I came across. I am so grateful to continue to know Ken Morris the teacher, mentor, and friend whose patient guidance has been so instrumental to the growth of my own academic tree. I'm honored to point out to my own students that the roots of our tree grow deep in the tradition of fundamental pharmaceutical sciences, stretching back to Sam Yalkowsky and George Zografi, but most firmly supported by the foundations that Ken taught me. In keeping with Ken's tradition, I try to introduce my students to their various academic relatives, and hope to learn the skills of an arborist that he has so clearly practiced over the years. Figure 4 depicts the most recent version of the Morris academic family tree. Emerging from Sam Yalkowsky's lab in 1987, it grew to include 16 PhD students as its branches. It would be impossible for me to include the myriad leaves and buds from all of the MS students, co-advisees, collaborators, and scientists that Ken has mentored over 3 decades.

In 2021, Ken returned to Arizona, where his tree was first rooted, and continues contributing to the field. Rumor has it that he got his band back together, and I have a standing offer to come out and jam with them next time I make it out that way. He remains my trusted mentor and guide as I pursue my own research questions, and tend to the growth of my lab. Most importantly though, Ken's tree serves as a reminder of his passion for science, his pursuit of materials understanding, and his desire to see that culminate in improvements in pharmaceutical processing and product quality. To paraphrase all of his former students, I end by saying thank you Ken for the profound impact that you have made on our respective contributions to science. Through your remarkable career as an advisor, mentor, and scientist,

you inspired our curiosity and challenged us to think differently. Most importantly, however, I am blessed to count you as an extraordinary friend, and hope to carry on the tradition of academic arborist.

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