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The T-Shaped Engineer as an Ideal in Technology Entrepreneurship: Its Origins, History, and Significance for Engineering Education

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The T-Shaped Engineer as an Ideal in Technology Entrepreneurship: Its Origins, History, and Significance for Engineering Education

From one perspective, the concept of T-shaped professionals who combine depth of technical expertise with breadth of knowledge appears to be but the latest iteration of the concept of the Renaissance or universal man (Gadol, 1973) as exemplified by Leonardo da Vinci. The T-shaped ideal, on the other hand, emerged in the early 1990s and seems to respond to the needs of information technology (IT) enterprises specifically and more generally of firms that seek to distinguish themselves for creativity and innovation. In its original incarnation (Palmer, 1990), what we now call the "T-shaped" individual or professional is described as a "hybrid manager" who combines IT skills with business skills. Twenty-five years later, one of the most frequently quoted papers on the subject (Demirkan and Spohrer, 2015) described the T-shaped professional as a worker who "has deep knowledge in just one area, but a good knowledge set and communication skills across many other areas." Demirkan and Spohrer also see the T-shaped metaphor more broadly as "an alternative paradigm for talent acquisition and management" (p. 13).

Although there are many different visualizations of the T-shaped ideal, the knowledge and competencies associated with the T-shaped professional, as represented in the figure below, are fairly well agreed upon.

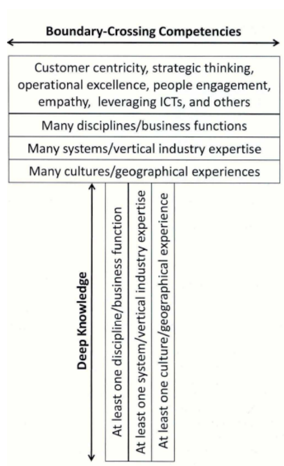

FIGURE 1. The T-shaped professional

(Demirkan and Spohrer, 2015, p. 13)

Publications taking the T-shape as their subject have been both numerous and varied in their depth, quality, and approach. From such a large and unwieldy discourse, it is difficult to get a comprehensive view or deep understanding, though it is very easy to see that the concept appeals to a diverse range of stakeholders. Within this vast literature, for example, it is unclear whether

- formal educational systems can "produce" such individuals;
- it is best to think in terms of T-shaped individuals, groups, organizations, or processes, or in altogether different terms; or
- the T-shaped ideal in technology entrepreneurship is something new versus the latest incarnation of long-standing discussions about the role of non-technical expertise in engineering education and practice.

As an initial step toward resolving some of these uncertainties, this paper outlines the chronology of the T-shaped ideal's development based on analysis of publications on the subject. Through a comparison of the U.S. and Germany, we explore the extent to which the enthusiasm for the T-shape is an American versus a global phenomenon. After presenting our research approach and numerical results, we sketch the history of the T-shaped ideal in publications in English and discuss why the German situation is different. In closing, we discuss some specific challenges of and barriers to achieving the T-shaped ideal and possible directions of future research.

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Research Approach: Quantitative and Qualitative Analysis of Publications Over Time

Insofar as we have been able to determine, no one has previously delineated more than small portions of the history we trace here. This paper presents the results of an initial, exploratory analysis in the domain of the history of ideas, which traces the origins and development of the beliefs that guide decisions and actions (see, for example, Skinner, 1969 and Bevir, 2000). The basic methodology of the history of ideas involves three distinct activities:

1. focusing on the emergence of **new terms** as an indication of broad cultural changes,
2. identifying **influential authors and publications** on those terms, and
3. correlating the emergence of terms and influential authors with **historical developments that might have motivated them.**

As Philip Wiener put it in his preface to his five-volume *Dictionary of the History of Ideas: Studies of Selected Pivotal Ideas* (1973), "the historian of ideas makes his [sic] particular contribution to knowledge by tracing the cultural roots and ramifications of the specialized concerns of the mind" (p. vii).

Search engines such as Google Scholar and databases of publications have made the quantitative analysis of large bodies of texts far less labor-intensive than it was in the days of card catalogues and print bibliographic resources. Although it is possible to do sophisticated assessments of the impact of publications, for this initial analysis we used a simple approach: an increase or decrease in the number of publications is taken as an indication of increasing or declining interest in a topic or idea. Such an approach is suitable because scholarship in the history of ideas seeks correlation rather than causation; the approach is advantageous because it makes it possible to trace the evolution of concepts not only over time but across disciplines and domains. In sum, what it lacks in specificity and causality, it makes up for in comprehensiveness and scope. Through literature searches, we also identified the earliest documented uses of the term and "landmark" articles, that is, articles that are frequently cited in discussions of the T-shape. We analyzed some of the content of the publications to gain insight into the motivations and conceptions of the authors and their audiences, but most of the evidence produced so far by our analysis is quantitative.

Although advocates of the T-shaped ideal often mention global competitiveness as a motivation for developing T-shaped professions, it is not clear to what extent the discussion is an international versus a distinctively American phenomenon. To get some sense of the scope of the conversation, we compared publications on the topic in English and in German, the languages in which we write, read, and publish. To get a sense of the distribution of national affiliations within the ASEE corpus of texts, we also looked at the author biographies of papers on the topic published in the ASEE Annual Conference Proceedings between 1996 and 2017. Most of the authors come from U.S. institutions. There was one article each with an author or co-author from these countries: Brazil, Canada, China, Denmark, Ireland, Scotland, Singapore, and Spain.

We used Google Scholar to search for the phrase "T-shaped professional." To identify articles in German we used the language options of the search engine. To find the explicit phrase, we used inverted commas. Additionally, we added a search for "T-shaped engineer" and "T-shaped manager." In February of 2018, a search for the phrase "T-shaped professional" yielded over 6000 results in English. In contrast, a similar search for articles in German yielded 14 texts total between 2010 and 2017. A search of various literature databases including articles from business, social sciences, and educational research produced only 18 articles in German. The databases encompass scientific papers as well as publications from the daily or weekly press. Fourteen of the eighteen articles were published in the daily press, and only four papers were journal articles. All 14 of the articles in the daily press originated with one author (Heinemann 2009) from a University of Applied Sciences who wrote one scientific article (in English) and gives regular talks at the chamber of commerce and similar institutions all over Germany. These presentations are usually covered in the local media. A general Google search for articles in German coming from Germany yielded 190 results total, with 64 designated as relevant and the remaining 126 more or less identical and redundant. These search results suggest that the enthusiasm for T-shaped professionals is an American enthusiasm, or at least a discussion mainly held in English.

Our qualitative analysis of these publications, as presented below, confirms that the discussion of the "T-shaped professional" in German lacks depth as well as breadth and volume. (See Appendix A for detailed results of German search.) Generally speaking, none of the articles in German is theoretically or empirically deeply rooted. The authors use the buzzword "T-shaped" and develop an argument about a new type of employee needed in a globalized and highly competitive economy. We did not identify a single article in the German discussion on the T-shape that explored it in depth or located it in the context of larger theoretical discussions.

Having concluded in the first phase of our quantitative analysis that the discourse on the T-shape appears to be primarily a conversation in English, we wanted to determine the extent to which that discourse takes place inside or outside of academia. As an initial exploratory analysis, we looked at two bodies of texts. The first was ASEE's PEER document repository, which includes all papers published in the proceedings of the ASEE annual conference from 1996-2017. We assumed that this body of texts is representative of the discussion of the T-shape as it pertains to engineering education in the U.S. We searched this repository using the search term "T-shaped" and got the raw data presented in Appendix B. We eliminated publications that used T-shaped to describe an object or junction (rather than an individual or a curriculum); the yielded data showed a big increase in papers on the topic between 2014 and 2015 and a significant increase in

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the number of divisions whose programs included papers on the topic between 2014 and 2017. These numbers are discussed in the following section of the paper.

To get a sense of the breadth of discussion of the T-shape in domains beyond engineering education, we analyzed the publications included in Spohrer's 2014 bibliography, "T-Shaped Professionals: Some References." This bibliography includes 121 items by 118 different teams or individual authors. The chart below shows the distribution of the papers in Spohrer's bibliography by year. Appendix C provides the raw data on publications for each year and lists the number of publications in the bibliography by individual authors and co-author groups, most of which appear only once. The most notable exception to this generalization are James C. Spohrer, who appears as author or co-author of 10 publications. A few authors (Bassano, Berile, Donofrio, Piciocchi, Saviano, and Weeks) are mentioned three times in the list.

Taken together, these quantitative results suggest that the discourse on the T-shape in English is quite broad and varied both inside and outside academia.

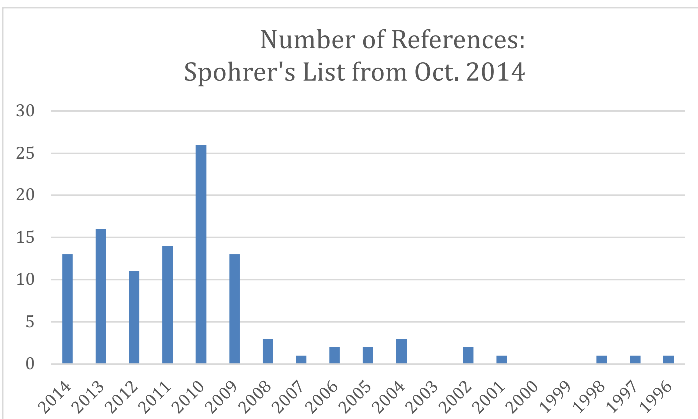

Figure 2. The distribution of papers in Spohrer's reference list by year (110 texts - 11 without year of publication). The data demonstrate the rapid increase between 2009 and 2010.

The History of the T-Shape in English: 1991-2017

Using the evidence described in the previous section, we established a timeline for the development of the T-shaped ideal in sources written in English. As an initial attempt at delineating important turning points in that development, we have divided the history into four phases, each of which is outlined in more detail below: (1) incubation (1991-2008); (2) rapid growth among stakeholders *outside* of ASEE (2009-2010); (3) slow but steady growth (2011-2014); and (4) rapid growth *within* ASEE (2015-2017). We also present hypotheses about the factors and events that may explain the trajectory of the T-shaped ideal's development.

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1991-2008: Incubation

The publications in this period indicate the emergence and early evolution of the term. The first documented (or at least most frequently referenced first) use of the term "T-shaped" as a description of a person appeared in a brief (693 word) newspaper article in *The Independent* (London) (Guest, 1991, September 17). Titled "Business Solutions: Managers in Focus as the Skills Gap Closes: The Hunt Is on for the Renaissance Man of Computing," the article draws on a number of different sources to support the claim that, at least in the U.K. context, "the personnel focus in computing has switched to the managers responsible for information systems within companies" (p. 1). This change in focus, in turn, is attributed to the increasingly important role of information systems within companies and a "divorce" or disconnect between information systems departments and "the pursuit of business goals." The article refers to a "controversial report" from the British Computer Society (BCS) that had been published the year before. That report, titled "'Hybrids'-A Critical Force in the Application of Information Technology in the Nineties" and authored by Colin Palmer (1990) draws extensively on research by Michael Earl and others at the Oxford University Institute of Information Management (1989 and 1990). The Oxford researchers had concluded that "in all the significant cases of successful implementation of information technology for competitive advantage or for achieving major change in organizations, there seemed to be a person at the heart of the development who displayed certain experiences and characteristics" (p. 232), as listed below.

Characteristics of the Hybrid Manager as Described by Earl and Cited in Palmer (1990), p. 232.
1. Understanding of the business and what was required within the business
2. Technical competence that enabled the manager to understand what was required in technical terms, including the scope of what was being planned
3. Organizational Skill #1: How to get about the business, and this implied that they knew the business and the people well
4. Organizational Skill #2: How to get things done, possessing a set of excellent social skills—to listen, understand, negotiate and persuade

Palmer emphasizes that "the hybrids were not operating in isolation" (p. 232), a nuance that was not captured in the article in *The Independent*, which focuses on the hybrid or T-shape as a *kind of person/individual*. This loss of nuance illustrates an important phenomenon in the discourse on the T-shaped ideal: a reductionist approach that transforms a rich and complex concept and body of research into a rallying cry for changing individuals rather than organizations.

The next landmark article appeared ten years later (2001) in the *Harvard Business Review,* "Introducing T-Shaped Managers: Knowledge Management's Next Generation" by Hansen and Oetinger. They describe an approach called "T-shaped management" that focuses on *the manager's behavior rather than the manager's skill set or knowledge base* [emphasis added]. The management approach as they delineate it includes several elements (1) the t-shaped *manager* who is primarily loyal to and responsible for an individual business unit, (2) a *management and incentive system* that promotes and disciplines "horizontal management behavior" and is "designed to change the managers' daily activities rather than the organizational structure in which they work," and (3) a *willingness to experiment*, adjust based on outcomes, and learn from experience.

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Hansen and Oetinger's article frames the discussion of the T-shape in terms of the knowledge economy and knowledge management, specifically, on mining "the wealth of expertise, ideas, and latent insights that lies scattered across or deeply embedded in . . .organizations" and "capitalizing on those intellectual resources—using existing knowledge to improve performance or combining strands of knowledge to create something altogether new" (p. 1). The authors draw their conclusions from examination of practices and outcomes at BP Amoco during the 1990s and focus primarily on a manager named David Nagel as a case study in T-shaped management. Where the report from the British Computer Society focuses on the need for T-shaped managers and the means for developing them, Hansen and Oetinger's treatment of the topic shows T-shaped management in action at the level of individuals *and* an organization as a whole. One other interesting aspect of Hansen and Oetinger's approach is their emphasis on the superiority of "direct personal contact. . .to effectively transfer implicit knowledge" (p. 2). Answering the question "why rely so heavily on managers to share knowledge?" they argue that "merely moving documents around can never engender the degree of collaboration that's needed to generate new insights" (p. 2).

The following year (2002), the first paper to use the term "T-shaped" in the sense we mean it was published in the proceedings of the ASEE Annual Conference. In "The Role of Masters Degrees in Technology and Business to Promote CPD for Engineering Professionals," B. R. Dickson from the Department of Chemical and Process Engineering at the University of Strathclyde in Scotland reports that "the MBA approach to career development is not the most relevant form of education and training for engineers" and argues instead for "*business training for the engineer*" [emphasis added] (p. 1). The author offers an alternative called "Integrated Graduate Development Schemes," which is described as "a Technical MBA, since it mixes advanced technical subjects with business management" (p. 7). These programs attempt "to meet the need for employment-based part-time learning within the context of continuing and professional development, providing core and advanced engineering knowledge & skills and encouraging a multi-disciplinary approach" (p. 1) in a context "where technical excellence and business impact can be matched" (p. 11).

Figure 3 below synthesizes the distributions of papers in Spohrer's bibliography and the ASEE conference papers, with the phases we have identified superimposed. As we have outlined above, the T-shaped ideal attracted attention outside of ASEE for at least ten years before it emerged as a prominent subject within ASEE. In the following sections we offer possible explanations for the rise of interest in the concept in the different domains represented by Spohrer's bibliography and the ASEE.

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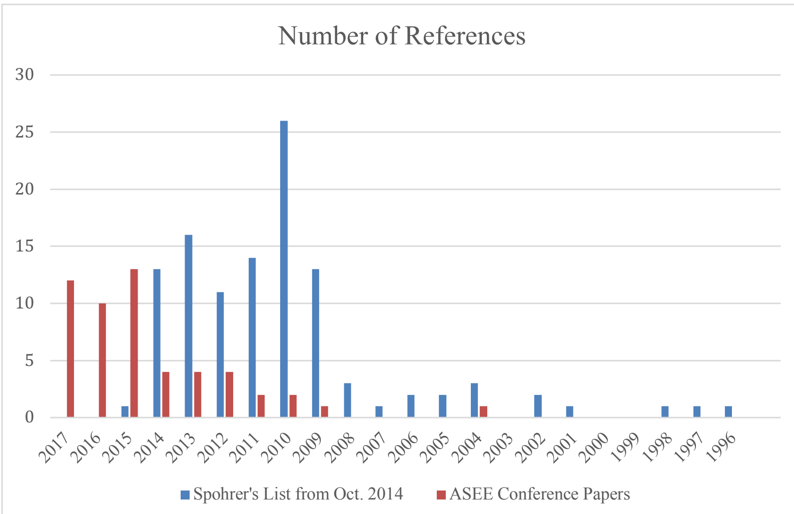

Figure 3. Synthesis of distributions in both bodies of texts (Spohrer’s list and the corpus of ASEE conference papers, with the phases superimposed. *Phase 1*: incubation: 1991-2008; *Phase 2*: 2009-2010: rapid growth among stakeholders outside of ASEE; *Phase 3*: 2011-2014: slow but steady growth; and *Phase 4*: 2015-2017: rapid growth *within* ASEE

2009-2010: Rapid Growth Among Stakeholders Outside of ASEE

As the data in Appendix B demonstrates, the number of papers published in the proceedings of the ASEE remained relatively small and constant through 2009. Outside of ASEE, however, there was rapid growth of interest in the T-shaped ideal. The most accessible and clearest evidence of this explosion comes from a bibliography on “T-shaped Professionals” that was compiled by Jim Spohrer of IBM in 2014 and published on Service Science: The Community Site for Service Science Education and Research. The yearly total of publications in that bibliography on the topic doubles from 13 in 2009 to 26 in 2010, before dropping back to 14 in 2011 and remaining relatively stable (in the 11-16 range) through 2014.

Our investigation of the drivers feeding this spike in publications suggests a confluence of factors:

1. Concern that the recovery from the Great Recession of 2008 was uneven and might not be complete. Several developments and events that were highlighted in year-end assessments for 2009 and 2010 provide evidence of this concern. *Time* listed “double-dip” as #9 on a list of the 10 most important buzzwords of 2009, and the Brookings Institution listed “achingly slow. . .progress toward full job market recovery” and austerity measures in the European Union as Top Economic Stories of 2010. In other words, there were some hopeful signs that the Great Recession of 2008 might be ending, but it was not clear that there would be a full economic recovery.

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2. The rise of China as a global economic power to be reckoned with. In its list of the five most important stories of 2010, the *Financial Times* listed the European debt crisis as #2 and "Chinese triumphalism" as #3. In a nutshell, "While the European and American economies struggled, China boomed."
3. Increased public awareness of and attention to high-tech entrepreneurs and their innovative products. In its 2010 Fast Facts, the U.S. Census Bureau highlighted the January 17, 2010 unveiling by Apple of the iPad tablet computer. *Time* named Facebook founder Mark Zuckerberg as the 2010 Person of the Year, and Tim Brown of IDEO stated in a widely circulated interview that the T-shaped professional would be the future of high-tech.

Perhaps coincidentally—but perhaps also tellingly—May 16, 2010 saw the space shuttle *Endeavor* take off on its last mission, which was also the second to last shuttle launch before the end of the space shuttle program. We hypothesize that these phenomena reflect a change in the creative and aspirational energies of the United States. To some extent, at least in the U.S. context, entrepreneurship seemed to be becoming the frontier that had previously been occupied by the space program.

These hypotheses are supported by further evidence that 2009-2010 saw the emergence of what might be called the "cult of the entrepreneur," a phenomenon in which entrepreneurship and entrepreneurs are viewed not only as the leading figures in business innovation, but also as contributing to economic recovery and solving social problems. A landmark article by Inge Oskam (2009) suggests that the cult of the entrepreneur was beginning to hold sway in academia as well as business. In the title for a conference paper "T-Shaped Engineers for Interdisciplinary Innovation: An Attractive Perspective for Young People as Well as a Must for Innovative Organizations," Oskam illustrated the extent to which the T-shaped person had become an aspiration and an ideal.

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Starting from the premise that "Dutch innovative capacity is lagging behind" and arguing that "T-shaped engineers are necessary for interdisciplinary innovation," Oskam's primary purpose in the article seems to be making the case for the Innovation Lab that her institution launched in 2008, a case for which there was no meaningful assessment data because the program had not yet finished its first year. Oskam's paper seems to be an early version of a kind of evangelical tone in which "T-style thinkers are [viewed as] the soul savers for organizational innovative drives and the allied change processes" (Kazmi and Naaranoja, 2015).

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2010-2014: Slow but Steady Growth

During this period, the number of papers published in the ASEE Annual Conference Proceedings grew slowly from 1 paper in 2009 to 4 papers from 2010-2013 and 5 in 2014 before increasing significantly in 2015. Another landmark paper was published in 2013, and, based on how often it has been cited in subsequent ASEE conference papers, exerted considerable influence and contributed to the phase of rapid growth that followed. That paper is Joe Tranquillo's "The T-Shaped Engineer: Connecting the STEM to the TOP" (Tranquillo, 2013). This is an inspiring paper with a lot of depth and fully developed examples, combined with insightful reflection. It treats the T-shape from philosophical, emotional, cognitive, and practical angles. His premise is that "most engineering curricula compartmentalize the depth and breadth into different classes" (p. 2), which means that the two parts of the T are not connected. One solution, he argues, is the development of T-shaped courses. In the article he describes two such courses: "Building Biomusical Instruments" (an example of what he calls extreme problem based learning) and "Brain, Mind, and Culture" (which exemplifies what he calls "radical disciplinary mixing"). Rather than focusing on the numbers collected as part of the evaluation of the course, he focuses on two categories of observations: (1) "stories of how students not only formed T-shapes but began to have genuine interest and engagement in another discipline" and (2) practical advice that can help other faculty overcome ideological and practical barriers to T-shaped courses (p. 2).

Both the breadth of knowledge that Tranquillo brings to bear in the paper and his biographical sketch provide insight into what allowed him to design, teach, and assess the learning outcomes of successful T-shaped courses: over 50 published or presented works in the field of engineering education; program building and prestigious fellowships and awards in biomedical engineering and leadership in technology and management; familiarity with educational psychology and classical philosophy; and a very broad range of interests including improvisational dance and music and brewing Belgian beer. If being a T-shaped engineer requires both breadth and depth, it appears that curricular innovation to develop T-shaped engineers may require even more of both, a challenge to which we return in the conclusion of this paper.

2015-2017: Rapid Growth Within ASEE

Over the last two years, the numbers really do tell the story. The number of papers on variations of the T-shape grew in both total number of papers and total number of divisions in which a paper on the T-shape was published:

- 5 papers in 3 divisions (2014)
- 13 papers in 10 divisions (2015)
- 10 papers in 8 divisions (2016)
- 12 papers in 10 divisions (2017)

The greatest amount of growth in both categories occurred between 2014 and 2015, and the numbers hold relatively steady in 2016 and 2017. Granted, many of these papers seem to use the T-shaped ideal as a framing device that establishes the merit of the curricular innovation or educational research presented in the paper, rather than developing the concept in depth or tackling the challenges of achieving the ideal in a curriculum. Nonetheless, there still appears to be a significant amount of creative curriculum design and rigorous assessment aimed at making the T-shaped ideal a reality.

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How and Why Is the German Discourse Different?

We began this research expecting to find more similarity than we ultimately did. This section of the paper offers a few possible explanations for how and why the German discourse is so different. The discussion about T-shaped engineers appears only as a very thin thread because the German literature on this topic is rare and not deeply grounded in theory. One reason for this small number may be inherent in the German educational system, including engineering education; it is tuition-free. This means that German institutions of higher education are not subject to intense market pressures and "customer demands" and have no impetus to create advocacy groups like the ASEE. In other words, university professors or lecturers have no forum that generates an intensive discussion about educating engineers, including the competencies,

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knowledge, and changing skills that are required for a modern engineering career. German engineering educators do not have the same incentives we see in the U.S. to provide serious legitimation for pedagogical approaches and educational goals. Some European discussions are held within the framework of the European Society for Engineering Education (SEFI – Société Européenne pour la Formation des Ingénieurs). SEFI mentions only seven Universities and Universities of Applied Sciences (out of a total of 118 institutional members) from Germany as members in their Annual Report 2016/2017 (SEFI 2017: 29).

Another reason for the lack of advocacy by institutions of higher education on the one hand and research institutes on the other is that German engineering education is strongly linked to the outstanding reputation associated with the brand "Made in Germany." German universities as well as firms recognize the high quality of German engineering degrees as given and indisputable. The brand "German engineer" (especially the "Diplom-Ingenieur") is an indication for the quality of the education delivered by the engineering programs.

As a result of these two factors, neither the academic community nor the Association of German Engineers (VDI) seems inclined to challenge established curricula and their outcomes, so we must look elsewhere for discussions related to the T-shaped ideal. The closest corollary to the T-shaped ideal has been the discussion since the late 1960s and early 1970s of the relationship between so-called "soft skills" and general education versus the technical expertise that is viewed as the core of engineering education. Following this thread of intellectual endeavor makes it easier to see both divergent and parallel developments in the U.S. and Germany.

After half a decade of discussing the so called "educational catastrophe" (Picht 1965), a number of writers were looking for approaches to modernize an outmoded education system. The situation is partly comparable to the Sputnik shock in the U.S., which led to numerous reforms in the educational system. In Germany, curricula appeared no longer prepared to offer skills to answer questions raised by the experiences of oil shortages or the structural unemployment that resulted from the advent of internationalization of industries such as textiles, shipbuilding, coal mining, and electronics. Moreover, a lack of appropriately trained engineers threatened the competitiveness of German industry.

Other concerns also suggested the need for reform in engineering education, concerns such as the inequality problem in the German educational system (Dahrendorf, 1965) and similar concerns about the English educational system (Willis, 1977). Both texts are landmarks in their field and asked for equal access to higher education. Furthermore, we see a broader trend in which writers and political activists questioned the post-war values that were dominant in West-European societies. Influential publications like Inglehart's *The Silent Revolution* (1977) reflected changing expectations about the development of technologies and a growing awareness of the social malleability of technology. Before this time, technological determinism had been the dominant view, and technology was seen as the main driver of economic and social development. Gradually, the technologically deterministic view lost at least some ground and was replaced by an understanding of technical innovation as the result of organizational decisions that in turn shaped the technologies produced. This new understanding stressed the responsibilities of engineers because it recognized the impact of engineers' decisions for or against certain technical solutions or options (Lutz, 1987).

Political debates in parliament in the early 1970s also provide insight into the changing

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influences and pressures on the German educational system. About 95% of the German Universities are public and, therefore, state funded. Debates about (engineering) education often show up in parliamentary agendas. We focus on a debate that took place in 1971 and was associated with a specific law that required that every University of Applied Sciences (UAS) in the federal State of Hesse to have a "Department of Social and Cultural Studies" (Sozial- und Kulturwissenschaften, SuK) and a "Department for Math, Natural Sciences and Data Processing."

The UASDarmstadt began as an upgrade of an engineering school. In 1976 the Christian Democrats asked the Social Democrat government several questions about the role of the social and cultural sciences in the engineering curricula of the UAS in Hesse. These questions got passed from the government to the presidents of the UAS, who in turn passed them along to the faculty councils of the Social and Cultural Science departments. The questions focused on two related issues: (1) Should all UAS have a comprehensive department of Social and Cultural Sciences? And, (2) should the government reasonably require a fixed percentage of courses delivered by comprehensive departments in the UAS?

The responses of the Darmstadt SuK-departments precisely articulated the connections between non-technical and technical portions of the engineering curricula at the UAS. The need as they saw it was "to interrelate the disciplinary education and the socio-economic circumstances in a given society in order to enable the students to critically reflect their occupational roles within a democratically organized society." The students, they thought, needed to understand "the interest driven character of economic and technical developments."

These sentiments notwithstanding, the main driver of the statewide establishment of Universities of Applied Sciences (comparable to the Polytechnic in the U.S.) was the need of industry to recruit employees with an engineering degree that could be easily adapted to the needs of firms. These firms wanted not a scientifically oriented engineer, but rather a research and development focused human resource. Starting mainly between 1969 and 1971, the UAS became very interesting for firms, especially for small and medium sized enterprises recruiting locally or regionally. This development can reasonably be interpreted as a first move towards an innovation-oriented engineering education (Mayer 1997; Teichler & Klumpp 2005).

A landmark publication was Mertens' text "Schlüsselqualifikationen: Thesen zur Schulung für eine moderne Gesellschaft" ("Key Qualifications: Thesis about Education For a Modern Society"; 1974). It advocates a move toward broad and less specific curricula that would better prepare the workforce to meet new demands. Mertens' text shows some similarities to discussions and facets entwined around the concept of the T-shaped professional. Although the paper does not mention "T-shaping" specifically, it emphasizes the value of combining specialist knowledge with more general knowledge to get a comprehensive perspective on the factors influencing decision processes or innovation projects. Disciplinary thinking is seen as limiting, because it tends to neglect the importance of competing values and motives. The key qualifications mentioned in Mertens' title facilitate the vertical transfer of ideas and help to reconcile competing requirements. Furthermore, this new set of qualifications enables the individual to understand contexts and to make decisions in situations that are risky and connected with high degrees of uncertainty. The most important qualifications for Mertens are the ability to apply structured thinking and empathy, which facilitates intercultural and intergenerational

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cooperation. Together, specialist and generalist competences enable life-long learning and help employees to adjust to new and changing demands.

Some of the German UAS and traditional universities responded to these calls to action. In the 1980s and 1990s we see the mushrooming of general studies programs and acknowledgement of non-technical skills in engineering curricula and engineering practice. Some institutions that implemented these teaching innovations gathered for three national conferences about models for and approaches to teaching general studies in engineering. The first was held in 2004 at the Bergakademie Freiberg, Germany; the second at the Bucerius Law School in Hamburg in 2010; and the third conference in November 2017 in Leipzig, Germany. These conferences are equivalent to the meetings of the Liberal Education/Engineering and Society Division of ASEE. All these conferences assembled a number of presenters who gave an overview of approaches towards general, integrated, or fundamental programs of study that most often dealt with non-technical subjects for engineers and, more rarely, with technical classes for students of social science programs. The non-technical (general studies) programs for engineers tend to focus on project management, presentation, or writing skills. Sometimes students have the obligation to visit three or four classes outside of their domain of studies without specification.

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The T-Shaped Ideal as the Intersection of Entrepreneurship Education and Liberal Education for Engineers

In the 15 years in which the discussion of the T-shape has been going on in ASEE, the largest numbers of papers have been presented in two divisions: Entrepreneurship and Engineering Innovation (10 total) and Liberal Education/Engineering and Society (9 total). In fact, the first paper on the T-shaped ideal was presented in the Liberal Education/Engineering and Society Division (LEES) of ASEE. The connection between the T-shaped ideal and technology entrepreneurship seems logical given that from the beginning the T-shaped discourse has been concerned with aligning engineering education to the purposes and needs of innovative businesses. Though the connection to LEES may be less intuitive, it may in the end be more important and may reflect a change in the way liberal education is justified as part of engineering education.

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The American literature shows a reframing from LEES (some fancy ideas of anxious social scientists and converted technical experts who criticize all new technologies) towards ENT (inevitable requirement for successful and modern innovation). While in the past a homeopathic dose of non-technical skills or some "soft skills" were enough "to water down" the hard science and engineering education, the innovation process now needs a full range of competencies which are much broader (including other disciplines), deeper (intercultural understanding and collaboration) and softer (empathy for the need of potential customers - Steffensen 2016).

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As we considered the discourse on the T-shaped ideal, we noticed that it is hard for authors to advocate for the T-shape without at least implicitly denigrating the I-shape (the individual with very deep knowledge of an engineering discipline). For example, in Germany, an individual with I-shaped expertise is called a "Fachidiot" (expert idiot, discipline idiot) (see: Oerter et al. 2012). In *Jurassic Park* (1990), Michael Crichton coined the term "thintelligent" to describe engineers who "think narrowly and . . .call it 'being focused.' They don't see the surround. They don't see the consequences" (p. 284).

Both ideas address or caricature an engineer who is taking a narrow view, not looking to the left or the right where issues of social responsibility, social justice, and unintended consequences come into view more easily. There has been an ongoing struggle in both Germany and the U.S. to fully integrate SuK and STS courses into engineering programs. The T-shaped ideal brings new insights and urgent needs. For example, non-technical skills are required for intrafirm collaboration across various departments. In a global economy, the competition is fierce and the technical solutions are not likely to succeed unless they are complemented by services to make the integration of the technical solutions smoother and more suited to the needs of particular businesses. Nevertheless, many engineers maintain a technologically deterministic outlook and still think that a brilliant technical solution will virtually sell itself.

In the accounts of Jim Spohrer, one the leading proponents of the T-shape, developing products that are *services rather than devices* requires a very different mindset which is reflected in the T-shaped ideal. In Spohrer's narrative (2017), the post-recession embrace of the service sector was a return to IBM's roots as a company that maintained machines and focused on solving customers' problems (as opposed to designing and manufacturing machines). Because interacting with customers and understanding their needs is such a big part of a service orientation, technical skills alone would not be adequate. IBM has invested tremendous amounts of time and money in propagating the T-shaped professional concept and doing research into it. The work of Spohrer and others provides evidence of the continuity between the T-shaped ideal and previous discourses both inside and outside of ASEE on a set of related topics, including liberal/general education, the integration of the humanities and social sciences into engineering education, and the "soft," "professional," or "contextual" skills, in other words, the non-technical expertise required for successful engineering practice.

There is no comparable discourse in Germany because the German effort toward complementing depth with breadth is relatively young; it appears that the important engineering schools still believe in the overwhelming superiority of the German engineering education. They bemoan the loss of the "Diplom-Ingenieur"-title. Getting the master's and bachelor's degrees instead, is not appealing. Especially the Diplom-Ingenieur" was a highly valued brand in itself (Schmachtenberg 2010). The testimonials on the homepage of the TU9 German Institutes of Technology (https://www.tu9.de/projects/3670.php) provide evidence of the extent to which Germany industry still embraces this sense of superiority. For example,

> "A 'Dipl.-Ing' in front of your name is like a star on the engine hood: A trademark of highest quality." (D. Zetsche, Chairman of the board of the Daimler AG)

> "The title Diplom-Ingenieur is not just a sign of the important tradition of the technology science in Germany but even more for the protruding and internationally recognized education." (M. Theissen, BMW Motorsports Director)

"Made in Germany" is still an argument and an indication for quality even though prices are important and Asian firms are competitive, especially when they sell products with good services. Twenty-five years ago, German products were often criticized for being over-engineered (see Herrigel & Sable 1999). After a period of economic downturn and crisis (Germany lost its strong economic position in Europe during the 1990s and got the title "sick man of Europe"), numerous social reforms as well as new work regulations lead to a change in attitude (Dustman et al. 2014). At the moment, Germany has one of the strongest economies in the world, based on engineered and high-quality products. Thus, Germany has not had economic incentives to modify engineering education. There have been reforms that responded to the problem of coping with heterogeneous groups of students, the changed quality of high school degrees, and new demands brought in by the digital natives. There has not, however, been a call for developing T-shaped engineers to meet the needs of innovative technology firms.

Conclusions and Future Research

Taken as a whole, the material presented in this paper leads to some fairly clear conclusions, some less well-supported but still plausible conclusions, and lots of questions that remain to be answered. In the category of clear conclusions, despite the almost ubiquitous discussion of the pressures of global competition, the T-shaping conversation is a distinctly and predominantly, though not exclusively, American phenomenon. The need for T-shaped engineers was articulated first by IT firms and experts who observed the problems and potential advantages of connecting technical expertise with business expertise. As IT became pervasive across sectors and industries, the T-shaped approach seems to have expanded with it, but primarily in the context of continuing professional development. In sum, interest in T-shaping began in professional societies, business firms, and consultancies and spread later to higher education, specifically engineering education for technology entrepreneurship.

The T-shape gained momentum as an ideal and an aspiration most recognizably around 2009-2010 as both the hope and the uncertainty of economic recovery from the Great Recession of 2008 drew lots of attention. During this same time, there appeared to be a shift of creative energies in the U.S. away from large-scale organizations and systems toward smaller organizations where individuals at least in theory have more influence and more opportunity to "make their mark." A less certain but intriguing conclusion is that the T-shaped ideal co-evolved as part of what might be called a "culture," or, more pejoratively, a "cult of entrepreneurship," a belief in the power of the entrepreneurial mindset to allow individuals and organizations to cope - and ideally, thrive - in an environment where lifetime employment is no longer a reasonable expectation and technology-based "disruptive" innovations heighten both potential risks and gains.

To return to one of the questions we posed at the beginning of this paper, it appears that the T-shaped ideal is both something new *and* the latest incarnation of long-standing discussions about the role of non-technical expertise in engineering education and practice. The discourse on the T-shaped ideal for technology entrepreneurship suggests that T-shaping may be a new way of talking about the deep contributions that the humanities and social sciences can make to engineering education. Put another way, the T-shaped ideal can reasonably be interpreted as an attempt to dissociate the breadth dimension of professional education from the "soft skills" that became the focus of many discussions in engineering education in the period leading up to and following the implementation of the EC2000 criteria. It may have prospered because it provides a new way for ENT and LEES to argue for non-technical content in engineering education by linking that content to economic growth.

Its obvious appeal aside, there are many challenges to overcome and questions to answer before the aspirations of the T-shaped ideal can be realized. It is not clear that formal educational systems can "produce" T-shaped professionals, especially at the undergraduate level. The T-shaped ideal emerged in the context of continuing professional development and of challenges

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The recovery, however, does not appear to have been the result of educational reform. Europe saw the Bologna-Reform that introduced in all member states the Bachelor and Master's degrees as the common final degrees in all member states. But

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that were apparent in the workplace but either absent or obscure in academic settings. And, even if formal educational systems could produce such individuals, it seems to take more than individuals with the requisite knowledge and competencies to achieve the outcomes the T-shaped ideal promises to deliver.

This reduction of the concept from a rich description to a shallow rallying cry is common in the discourse on the T-shaped ideal. One implication of this observation is that anyone who wishes to acquire T-shaped expertise for him- or herself, or develop it in others, would do well to become familiar with the research base that gave rise to the T-shaped ideal and continues to evolve. Another challenge is that the abilities valued in the T-shaped professional do not correspond clearly with the disciplinary structures of academic institutions or the expertise of faculty. The competencies of one of the leading authors Tranquillo, described before, indicate the need for a broad set of competencies on the part of the educating professors. To highlight the challenge: In both the German academic system and the American system, industrial/systems engineering programs are popular, in part because they reduce the pressure for students to decide what they will be in the future. These programs are a step towards T-shaping, but the curricula often fail to integrate technical and business concepts. The two parts of the programs remain columns of knowledge held in parallel without much contact and integration. The disciplinary realms are kept apart, being additive at best in the end. An education following the ideal of producing T-shaped engineers, managers, or professionals asks for a truly integrated curriculum and teaching approach. Furthermore, descriptions such as "lifelong learners with open minds who collaborate easily across their local and global networks," "empathetic communicators," "deeply engaged, critical thinkers," and "entrepreneurially minded opportunity finders with imagination who learn quickly from failure" suggest individual virtues (personal qualities) rather than bodies of knowledge or the use of standardized approaches.

The last chapter in the chronology we have traced here is, as astute readers may have noticed, rather underdeveloped. There is much more to be learned from the relatively recent history of the T-shaped ideal in technology entrepreneurship, especially the aspect of that history that can be discerned through qualitative rather than quantitative analysis. We look forward to contributing to that enhanced understanding and hope that others will join us in the endeavor.

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Appendix A. T-shaping in the German Educational System

As mentioned in the beginning, Germany has no institution like the ASEE. Therefore, the literature analysis about the state of the art of research and publications covering the toping "T-shaped professionals" looks at various databases including articles from business, social sciences and educational research. The analysis produced 18 articles in German. 14 were published in the daily press (the origin is one professor from a University of Applied Sciences who gives regular public talks at the chamber of commerce and similar institutions all over Germany. These presentations are usually covered in the local media). 4 papers were journal articles. The authors use, or better, mention the term without developing a concept, summarizing the idea of combining the specialist and the generalist as a suitable option to cope with future demands.

Daily press: 2016 (4);
2013 (2);
2011 (6);
2010 (2)

Journals: 2011 (2);
2010 (2)

Going down the "quality level": Google scholar found 14 texts in German talking about "T-shaped professionals":

2010 (2)
2011 (1)
2014 (2)
2015 (2)
2016 (2)
2017 (4)

Topics mentioned are

- Design thinking (3)
- Software and IT (4)
- Agile Organizations and SCRUM (3)
- Internships (3)
- Complementor Relations Management (1)

Topics of the 64 relevant matches out of 190 google matches for German

- Translations and dictionaries, pictures (4)
- XING, LinkedIn (5)
- Job search and offers (7)
- Consultants (~ 20)
- Blogs (4)
- Professional information platforms (5)
- HR (8)
- Book chapters (4) – all from one book, the professor mentioned above.
- And others (7)

Appendix B: Search Results for "T-Shaped" in ASEE Conference Publications

Raw Numbers of Papers by Year

2017 (15)
2016 (14)
2015 (16)
2014 (5)
2013 (4)
2012 (4)
2011 (4)
2010 (4)
2009 (1)
2007 (1)
2006 (3)
2005 (1)
2002 (1)

Raw Numbers of Papers by Division

- Architectural (1)
- Biomedical (1)
- Chemical Engineering (1)
- Civil Engineering (2)
- College Industry Partnerships (1)
- Community Engagement Division(1)
- Continuing Professional Development (1)
- Design in Engineering Education(6)
- Division Experimentation & Lab-Oriented Studies (4)
- Educational Research and Methods (2)
- Energy Conversion and Conservation (3)
- Engineering Design Graphics (1)
- Engineering Leadership Development Division (2)
- Entrepreneurship & Engineering Innovation (10)
- Environmental Engineering (1)
- Graduate Studies (3)
- Liberal Education/Engineering & Society (9)
- Manufacturing (1)
- Minorities in Engineering (1)
- Multidisciplinary Engineering (3)
- Ocean and Marine (1)
- Student (1)
- Systems Engineering (1)
- Technological and Engineering Literacy/Philosophy of Engineering (3)

Appendix C. T-Shaped Professionals: Some References

SERVICE SCIENCE
Community site for Service Science Education and Research T-Shaped Professionals: Some References
Posted by Jim Spohrer on 30 October 2014, 1:27 pm

1. Publications by Year Listed in the Bibliography by Jim Spohrer

2014	13
2013	16
2012	11
2011	14
2010	26
2009	13
2008	3
2007	1
2006	2
2005	2
2004	3
2003	0
2002	2
2001	1
2000	0
1999	0
1998	1
1997	1
1996	1
no year	11

2. Publications by Author Listed in the Bibliography by Jim Spohrer

Count	Author	Number of References
1	Afeez_Baig, Gururajan, R.	1
2	Albornoz Pardo, C.	1
3	Allenby, B.	1
4	Asgary, N., & van den Heuvel, W. J.	1
5	Badinelli, R. D., Polese, F., & Mele, C.	1
6	Bailey, D. R., & Tierney, B.	1
7	Bailey, M.	2
8	Bardecki, M.	1

9	Barile, S.G. Franco, G. Nota, M. Saviano	1
10	Barile, S.G., & Saviano, M.	1
11	Barile, S.G., Saviano, M., & Simone, C.	1
12	Berger, W.	1
13	Bissett, K.	1
14	Borangiu, T.,Curaj, A, Dodar, A.	1
15	Borrell-Damian, L., Brown, T., Dearing, A., Font, J., Hagen, S., Metcalfe, J., & Smith, J.	1
16	Botella, P., & Sancho, M. R.	1
17	Bouma, J.	1
18	Bourne, L., & Walker, D. H.	1
19	Bullen, C. V., Abraham, T.,	1
20	Bullen, C. V., Abraham, T., Gallagher, K., Simon, J. C., & Zwieg, P.	1
21	Campbell, A.	1
22	Chiu, C. H., & Liu, M. F.	1
23	Cunha, J. F., Hocová, P., Patrício, L., Staníček, Z.	1
24	Cutler, T.	1
25	de Grandbois, Y.	1
26	Dickson, D. R., & Ford, R. C.	1
27	Dickson, D., Noveski, I., Hamidi, H	1
28	Donofrio, N., Sanchez, C., & Spohrer, J.	1
29	Donofrio, N., Spohrer, J., & Zadeh, H. S.	2
30	Dotger, B.	1
31	Dougherty, D., Clegg, S. R., Hardy, C., Lawrence, T. B., & Nord, W. R.	1
32	Drummond, S., Carr, V., Young, A., Brotherston, L.	1
33	Elia, G.	1
34	Elia, G., Poce, A.	1
35	Elmquist, L., & Johansson, G.	1
36	Felmingham, S.	1
37	Fisher, A., Jiang, L., Vargas, V.	1
38	Fleischmann, K., & Ward, L.	1
39	Gabriel-Petit, P.	1
40	Gardner, P.	1
41	Gardner, P., Gross, L., & Steglitz, I.	1
42	Gerson, P. M., & Ramond, B.	2
43	Grasso, D., Burkins, M. B., Helble, J. J., & Martinelli, D.	1
44	Hafkesbrik, J., Bachem, C., & Kulenovic, D.	1
45	Hansen, M. T., & Nohria, N.	1
46	Hardin, D., Westcott, M., & Berno, T.	1

47	Harkins, M.	1
48	Harris, H., Murphy, S., & Vaisman, M.	1
49	Heinemann, E.	1
50	Helmi, A.	1
51	Hirst, L.	1
52	Hook, S. A.	1
53	Hyung-Jin Park, M., Lim, J. W., & Birnbaum-More, P. H.	1
54	Joffy, T.; Purani, K.	1
55	Johansson, G., Elmquist, L.	
56	Kamp, A., & Klaassen, R.	1
57	Kang, S. C., Liu, P. L., Lee, Y. F., Ye, S. R., Yang, H. J., & Peng, C. W.	1
58	Karjalainen, T. M., Koria, M., & Salimäki, M.	1
59	Kim, J., Warga, E., & Moen, W.	1
60	Kovács, G., & Tatham, P.	1
61	Lemmink, J. G., & Chatterjee, J.	1
62	Lindberg, T., Meinel, C., & Wagner, R.	1
63	Lohr, S	1
64	Macaulay, L., Moxham, C., Jones, B., & Miles, I. (	1
65	Madhavan, R., & Grover, R.	1
66	Malone, D.	1
67	McIntosh, B., Pascoe, M., Lant, P., Bunn, S., Jeffrey, P. J.	1
68	Miller, S.	1
69	Missingham, B., & McIntosh, B. S.	1
70	Motta, G., Barroero, T., & Pignatelli, G.	1
71	Mukhtar, M., Yahya, Y., Abdullah, S., Hamdan, A. R., Jailani, N., & Abdullah, Z.	1
72	Müller, O., Schmiedel, T., Gorbacheva, E., & vom Brocke, J.	1
73	Oskam, I. F.	1
74	Ouyang, Q. C., Stephen, P., & Jim, S.	1
75	Pathirana, A.	1
76	Pelz, J., Köhler, W., & Peters, H.	1
77	Peters, J.	1
78	Pingback	1
79	Pun, S.	1
80	Rip, A.	1
81	Robotham, A. J., Raine, J. K., Nates, R. J., White, D. E.	1
82	Sandeen, C. A., & Hutchinson, S.	1
83	Sandweiss, D., & Delcourt, S.	1
84	Sekhon, J. G., & Mathews, C. T. (	1

85	Silver, D., & You, A.	1
86	Smith, B.L.	1
87	Spohrer, J., Giuiusa, A., & Demirkan, H., Ing. D	1
88	Spohrer, J., Golinelli, G. M., Piciocchi, P., & Bassano, C.	1
89	Spohrer, J. C., Gregory, M., & Ren, G.	1
90	Spohrer, J., & Kwan, S. K.	1
91	Spohrer, J. C., & Maglio, P. P.	1
92	Spohrer, J., Piciocchi, P., & Bassano, C.	1
93	Spohrer, J., Sianob, A., Piciocchi, P., & Bassanoc, C.	1
94	Subramanian, K., & Rangan, U. S.	1
95	Sussman, J. M.	2
96	Tatham, P. H., Kovács, G., & Larson, P. D.	1
97	Tomé, E.	1
98	Traver, C.	1
99	Tsunoda, M.	1
100	Tuck, P.	1
101	Uden, L.	1
102	Uhlenbrook, S., & Jong, E. D.	1
103	Veit, D. J.	1
104	Viia, A., Terk, E., Lassur, S., Kaivo-oja, J., & Kuosa, T.	1
105	von Oetinger, B.	1
106	Weeks, F. H., & Weeks, R. V.	1
107	Weeks, R. V.	2
108	Weeks, R.V., & Benade, S.	1
109	Williams. B.A.	1
110	Winberg, S.	1
111	Winograd, T., & Klemmer, S.	1
112	Wodo, W.	1
113	Workforce, T. P. T. S. S.	1
114	Yahya, Y., Mukhtar, M., Saidin, H., & Malaysia, Z. A.	1
115	Yeh, Z. T., & Mei, H.	1
116	Yongqi, L.	1
117	Young, A., Bill, A., & de Freitas, N.	1

3. Spohrer's List of Publications (121 texts)

Deleted: The

Note: For reasons we cannot fathom, the original list was not in alphabetical order by authors' last names. We have reformatted it for the reader's convenience. We also corrected a few misleading information of the references.

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I hope the changes I made here make sense to you. I was trying to make the logical links more explicit.