AC 2011-2091: EXPLODING PIPELINES: MYTHOLOGICAL METAPHORS STRUCTURING DIVERSITY-ORIENTED ENGINEERING EDUCATION RESEARCH AGENDAS

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Exploding pipelines: mythological metaphors structuring diversity-oriented engineering education research agendas

Abstract
Critics have established there are major methodological flaws with using pipeline as a metaphor for structuring research studies that investigate the underrepresentation of certain groups from engineering faculty; yet pipeline remains the predominate metaphor in engineering education research on underrepresentation. We find it important to remind the engineering education research community of the theoretical and methodological limitations of homogenous reliance on one metaphor to guide research studies. This paper critically explores the discourse of "pipeline" as an aim to (re)introduce to engineering education researchers both the method of discourse analysis as well as alternative metaphorical frameworks. We use empirical data collected for ADVANCE Purdue's Academic Career Pathways study using oral history and participatory research methods to explore the consequences of pipeline metaphor's predominance. These data are the academic stories of STEM faculty and help us explore: 1) what theoretical or methodological advantages and disadvantages does pipeline metaphor afford researchers? and 2) how does pipeline metaphor highlight or mask the lived experiences of women working in engineering academic contexts? We find these methods more suited to women's small numbers and lend themselves to understanding local conditions – individual departments, colleges, and universities and we suggest advantages to alternative metaphorical frameworks. We conclude that an *ecosystem* of metaphors would help us understand the complexity of women's career paths in engineering academia and move engineering education research beyond the linear model of the pipeline metaphor.

Introduction

Over thirty years after Sue Berryman[1] used the pipeline metaphor for understanding the underrepresentation of women and people of color in STEM disciplines, the pipeline remains the dominant theoretical framework on which diversity-oriented engineering education research is based. The use of "pipeline" is arguably the dominant metaphor used to understand the underrepresentation of certain groups and has reached almost mythological proportions in both its broad reach and in how it engenders fairly uncritical allegiance from many researchers studying women's underrepresentation in engineering. This reliance on pipeline metaphors continues despite considerable external critique of the model argued from researchers both inside and outside the engineering education research community.

In this paper, we pose and answer questions about the consequences of this metaphor's predominance, including: 1) what theoretical or methodological advantages and disadvantages does this metaphor afford researchers? and 2) how does it highlight or mask the lived experiences of women working in engineering academic contexts? In addition, we ask perhaps more controversially how the reluctance to release pipeline theory from its hegemonic stronghold might reflect engineering education's larger disciplinary reluctance to review their current structure and reconstruct themselves into institutions that are more egalitarian?

This paper critically explores the discourse of "pipeline" as an aim to (re)introduce to engineering education research both the method of discourse analysis as well as alternative

metaphorical frameworks. We ground this paper's theoretical discussion in the empirical data collected for ADVANCE Purdue's Academic Career Pathways study, a research project that uses oral history methods and participatory frameworks to collect and study the academic stories of white women and faculty of color in STEM disciplines.

We will begin by highlighting three notable critiques of "pipeline theory," identifying intersections and overlaps. We then describe a set of theoretical and methodological limitations put into context with some advantages. We use data from our study to explore the second question of how the metaphor highlights or masks lived experiences, and share the metaphors our study participants used to describe their own careers. We describe future research directions with this study, and end the paper with a plea to develop an *ecosystem* of metaphors to understand the complexity of women's career paths in engineering academia.

Pipeline metaphor explained

When explicitly cited, the pipeline metaphor is often introduced simply in the title, background section, or keywords of a paper,[2-7] or as a casual aside in a magazine article,[8-10] less so as an explicit theoretical construct that researchers are choosing to invoke to structure their work. However, "pipeline" remains a key metaphorical concept that helps structure thinking as well as subsequent policymaking in and around engineering education.

In their landmark book *Metaphors We Live By*[11] Lakoff and Johnson argue the following about the use of metaphor in normal human communication (quoted at length from p. 3):

> Metaphor is for most people a device of the poetic imagination and the rhetorical flourish – a matter of extraordinary rather than ordinary language. Moreover, metaphor is typically viewed as characteristic of language alone, a matter of words rather than thought or action. [...] We have found, on the contrary, that metaphor is pervasive in everyday life, not in language but in thought and action. Our ordinary conceptual system, in terms of which we both think and act, is fundamentally metaphorical in nature.
>
> The concepts that govern our thought are not just matters of the intellect. They also govern our everyday functioning, down to the most mundane details. Our concepts structure what we perceive, how we get around in the world, and how we relate to other people. Our conceptual system thus plays a central role in defining our everyday realities.

Lakoff and Johnson go on to describe at length how metaphors structure and systematize conceptual ideas, noting Reddy's argument[12] that we (speaking English) make use of a "conduit metaphor" which can be used to see how language structures language: "The speaker puts ideas (objects) into words (containers) and sends them (along a conduit) to a hearer who takes the idea/objects out of the word/containers." (p. 10) They provide many examples, including: "It's hard to *get* that idea *across to* him." (p. 11). We see this structure helpful in thinking about the pipeline metaphor – another conduit metaphor – and its limitations.

We acknowledge that "pipeline" has been a powerful and helpful metaphor for thinking about women's experiences in becoming engineers and scientists. In this context, "pipeline" models the educational and employment systems in the United States. Unmade "pre-scientists and

engineers" enter the pipe and proceed through the pipeline (spending time in educational systems) until the pipe's outlet, where they exit as fully formed engineers and scientists and are employed in the paid workforce. If the volumetric flow rate at the pipe's outlet is different from that at the pipe's inlet, it is because some liquid "leaked out" along the way. This metaphor has been helpful for looking at some structural inequities in women's education.[13]

However, we feel the majority of contemporary writers and scholars who employ this metaphor do so without explicitly noting its limitations. Although it seems obvious here, we feel it important to say women's educational and employment experiences *do not actually* involve climbing through (or being swept willy-nilly through) a pipe. In other words, the metaphor is helpful for thinking about *some aspects* of women's experiences, but not others. We have begun to professionally worry that the engineering education research community has largely forgotten that we need to *still investigate those other experiences.*

Existing critiques

We are far from alone in this criticism of using pipeline as a metaphor to understand women's educational and employment experiences in STEM fields. From among many, we will highlight three notable critiques: Metcalf[14] has done a marvelous job describing both the model and its major critiques, as well as situating it within alternative theoretical frameworks; Xie and Shauman[15] are well recognized for their meticulous quantitative analysis that demonstrates theoretical limitations of the pipeline metaphor; and Allen and Castleman[16] provide a perhaps less well known but equally thoughtful critique to what they call the "pipeline fallacy."

Although it is the most recent publication, we will begin with Metcalf as she provides the metaphor with a clear introduction. Metcalf[14] argues:

> [the metaphor,] based on supply-side economics, flow modeling, and social engineering was designed by engineers and the National Research Council's Committee on the Education and Utilization of the Engineer. Depicted as a balance equation, the model describes the linear sequence of steps necessary to become a scientist or engineer and shows the large numbers of scientists and engineers that would be needed to maintain national competitiveness. Over a set time period (e.g., one year), the model attempts to quantify the flow of people who move from an entry pool of secondary school students admitted to higher education institutions, to students engaged in educational preparation for STEM occupations, to employment in the STEM community, and followed by temporary or permanent departures from the STEM community. (p. 2)

For those interested in the balance equation used, Metcalf[14] quotes the National Research Council's formula: "$Q_1 + \sum f_i + \sum f_o = Q_2$, Where Q_1 = the number of people in stock at the beginning of the period, $\sum f_i$ = the sum of flows into the stock, $\sum f_o$ = the sum of flows out of the stock, and Q_2 = the number of people at the end of period."[17]

Metcalf spends the rest of her paper systematically reporting and expanding upon various different critiques, including those that Xie and Shauman[15] provide (below). However, we want to point out two key ideas from this paper: first, Metcalf notes that it is not always clear what "counts" as a career in engineering or science. Others have also noticed this bias that the pipeline

always seems to "end" in bench science, government or academic science or engineering, engineering industry, and other "big science" enterprises, rather than teaching of science or engineering in public schools, in science and engineering outreach or journalism, or in community activism.[18]

Second, Metcalf notes that pipeline homogenizes the experiences of women as impacted by race and class – in other words, the lived experience of women from different racial and ethnic groups and from different socioeconomic classes is erased when all women are pushed through the same pipeline. And indeed, in a country where public education systems (both K-12 and higher education) still seem organized by race and class, what then does the "pipeline" represent?

Xie and Shauman[15] note three main concerns with pipeline metaphors: firstly, they argue that the pipeline models a "unidirectional, orderly, and rigid series of stages, and it equates noncompliance with the normative career trajectory to 'leaking' or 'dropping out' of the pipeline." (p. 8) This results in overlooking, for example, potential entrances of non-traditional-aged women into the educational pipeline, or the possibility of women transferring in from other fields, or the inclusion of women who, mid-stream, decide to take a different educational or career path for some years, and then later decide to return. Secondly, the metaphor suggests "a developmental framework in which the successful completion of all stages within an ideal time schedule means a positive outcome." (p. 8) This, of course, is flawed as women who have successfully completed the educational pipeline requirements are assumed in some contexts to be a success, whether or not they decide to enter a scientific or engineering-related profession. Finally, they argue "other life course events, such as family formation, that coincide with the science career trajectory are absent from the pipeline conceptualization… As a result, past research is mainly individual-centered and overlooks the role of the family, whereas gender differences in family expectations and the demands of familial roles may have a significant impact on the timing and sequencing of women's science careers." (p. 9)

Through an investigation of the Australian higher education system, Allen and Castleman[16] demonstrate that pipeline is not used only in US contexts to understand women's careers, but in other countries as well, with its difficulties intact. They argue:

> The pipeline argument rests on the notion that there is an unavoidable time lag between policy change and organizational change... The traditional argument has been that women's position in higher education is slowly but steadily improving in response to their increased educational achievement, unproblematic change, and the decline of gender discrimination in hiring, promotion and tenure. [...] What is particularly interesting about the model that sees the academic pipeline beginning with qualifications ... is that it assumes a mechanistic and unconnected university context. In fact, universities have a great deal of control over both the supply and the demand of for academic labour. A completed PhD is typically the result of collective as well as individual endeavor. (p. 152-154)

We see Allen and Castleman's point as well suited for the American context of faculty work as well as the Australian PhD experience. The key point that pipeline justifies the time lag between policy change and organizational change, and that patience will be rewarded with a remediated system is one we have not seen elsewhere.

Allen and Castleman's list of problems with this metaphor are similar to Metcalf and Xie and Shauman's arguments; however, they add two additional important critiques:

> [first]... its failure to acknowledge the complexities of male advantage, gender power, and the gendered nature of organizational dynamics and the implications of organizational change, particularly in relation to restructuring. To embroider the metaphor, the 'pipeline' is not uncontrolled. It contains valves and holding bays, deviations and constrictions and it leaks women.
>
> [... Second] is its implicit incorporation of a simple human capital approach to labour markets. Many of the pipeline explanations focus on education, qualifications and formal preparation and thus imply that the central issue is women's worthiness for available jobs and promotion... the issue is couched in terms of bringing women up to a standard where they can compete on equal terms with males in the labour market. There is little acknowledgement of gender segmented labor markets... or gender bias in definitions of merit... The pipeline argument assumes that, in general, recruitment, promotion and the labour processes are rational and neutral organizational practices. Human capital analyses are problematic in explaining women's location in the workforce and perpetuate the deficit model of gender inequality. (p. 156-157)

Taken together, these three sets of critics point out major methodological flaws in using pipeline as a metaphor for structuring research studies:

- Most studies do not articulate what counts as a "successful" scientific or engineering career. Must a person remain in the same profession for her entire working life for her to be considered "in" the pool? Or might there be more "kinds" of scientific-related careers that should "count" than that of bench scientist or design engineer?[18]
- Assuming that "gender effects" on career choices can be studied independently of race and class overlooks considerable research in the social sciences about the intersectional[19] nature of such (and other) categorizations, all of which individual people experience in their daily lives;
- The metaphor of pipeline overlooks real patterns in people's careers that are particularly important for understanding *women's* careers (and indeed perhaps women of color's careers);
- The "time lag" built in to pipeline theory has now failed to produce gender parity in engineering professions despite our waiting for multiple "educational generations" of women to work their ways through.

What theoretical or methodological advantages and disadvantages does this metaphor afford researchers?

At its heart, a "pipeline" is a physical metaphor that speaks to engineering expertise. We as engineers have affinity with the language of the metaphor, understand the real-world nuances implicit in friction against pipe walls, flow rate, flow profiles, and so on. We understand flow velocity increases when the pipe diameter decreases. Yet with this expertise, we can also add some of the metaphor's more significant limitations:

- People do not act in the same ways that fluids act;
- The difference in volumetric flow rates in a pipeline is understood through the concept of "leaking," but leaks occur randomly (in the sense that the volumetric unit that leaks out is not making choices to leak out); individual people do not exit a career path randomly.
- In pipelines, when fluids re-enter a pipeline, it is usually as "contamination." Reentering a career path later in time (a common path for many women) should not be thought of as "contamination."
- Unless they are plug flow reactors, fluids usually should not change significantly as they flow through the pipe; in contrast, we hope people learn and change as they move through the educational system.

The methodological and theoretical disadvantages are becoming more and more clear. But with so many published and obvious critiques of the flaws of "pipeline," why is it still used? To better understand this, we also need to ask the question of what theoretical or methodological advantages this metaphor affords researchers.

Theoretically speaking, we believe pipeline remains a popular guiding metaphor in part because we have a practice of building new scientific theory on the foundations of older theories (Kuhn notwithstanding). At this point, there have been decades of research investigating women's underrepresentation in STEM disciplines, and much of the early works (including Berryman as well as other well-respected researchers such as Rosser[13]) make use of the pipeline metaphor. We have a research practice of citing past research as motivations and justifications for new, which perhaps makes it difficult to get away from the metaphor.

Indeed, the metaphor remains popular also in part because the decades of existing research have helped the metaphor move into a "common sense" frame of reference – upon authors' invoking it in those same magazine articles or journal background sections, they rarely connect it with citations to recognize the metaphor's provenance. In this way, "pipeline" no longer represents an idea we want to communicate; as Lakoff and Johnson would argue, it has *become* the way we think.

Methodologically, the pipeline affords researchers a clear set of experiences to investigate: the places where "leaks" occur, analogized to decision points along one's career path. However, the solutions are therefore conceived of as "patching the leaks," with the actual construct of the pipeline never questioned. In other words, this model is "safe" and relatively non-threatening or non-controversial because it relies on a metaphor of fixing a problem, not redesigning a system – we just need to fix the problems with the pipeline, rather than rip the whole thing out and install an elevator.

In a similar way, researchers interested in investigating large numbers of people can model a complete pipeline (from pre-kindergarten to retirement) because of their point of reference "outside" of it, and looking back at the group-level experiences of those "inside" of it. Looking at the group level of analysis lends itself to statistical methodologies, trying to understand the characteristics of the sample and whether differences with the general population are a result of chance or some more "real" cause. However, rather than looking at a lifespan of many people in groups, perhaps this complex problem requires understanding the pipeline "cross-sectionally" –

for example, starting with an individual inside the pipeline, understanding the groups she is a part of, and how they form institutions and how the institutions are reified into structures. In effect, to understand women's comparatively low numbers, we need research using *multiple* units of analysis, including micro (at the level of an individual), meso (at the level of institutions) and macro (at the level of social structures like gender) levels of research.[20]

The advantages so far might seem a result of history, habit, and inertia. However, there is a potentially more insidious advantage. Focusing on pipeline has not fundamentally changed our practices within engineering education institutions because of all of its conceptual flaws we have discussed earlier, *but also* perhaps because the constructors and members of those institutions *do not want to change.* Amy Slaton makes this argument in the context of increasing the number of Black students in engineering schools in her excellent book, *Race, Rigor and Selectivity*.[21] She points to the metaphorical language of "pooling" (which fits in well to the pipeline metaphor – the "pool" is at the outlet of a stage of the educational process), and notes that arguments around academic quality and standards always arise in the conversations about increasing the number of students of color in engineering undergraduate programs, usually as a reason *not* to make a particular policy decision. We quote at length this part of her argument:

> It is exactly the nature of the "pool" [of qualified ethnic minority students graduating from high school] that requires historical analysis if we are to understand the ongoing underrepresentation of African Americans in engineering. If a student arrived at the end of high school without having achieved visible and conventional measures of academic success, he or she was not invited into the world of higher engineering education. This was disproportionately the case with minority students who made up the majority at underfunded, inner-city high schools.... Thus, to mandate the admission of only qualified and not qualifiable students put the burden of integration on a part of the education system that patently was not doing its job. [...] What would have happened if institutes of technology and universities, given enough support and sanctioning by employers of their engineering graduates, took over the task of remedial education? Schools could conceivably maintain sound material standards for engineering but train students over longer periods, with greater provisions for remedial instruction. Even if such instruction costs more than existing approaches, why have educators and policy makers historically not found it worth expending such resources to correct a social inequity? (p. 100)

Slaton goes on to argue persuasively how the existing educational system composed largely of white elites will remain in the power of these same elites when we base our arguments on maintaining academic standards and absolving ourselves of the responsibility to help those in under-resourced school districts to meet those standards. Maintaining this fiction also helped white administrators maintain the status quo; the power for changing the fictional approach remains in the hands of those who would lose power if things improved.

And so we analogize to the context of gender and engineering: if women are not coming out of pipeline in sufficient numbers or of sufficient quality, why not do something on the hire end to improve pool? If women are not qualified sufficiently to serve in faculty positions in STEM disciplines, universities could develop ways to help qualify them. If the numbers are too few graduating from other universities with their PhDs, universities could find a way to graduate

more and hiring their own. If women drop out of the workforce to raise families, universities could find ways to keep them engaged and hire them back down the road. Of course, there are reasons for why these are inappropriate, and they also often put diversity at odds with "quality" in the same way that Slaton argues.

We recognize this is a rather functionalist argument,[22] implying that the system does not change because there is some advantage from it not changing. While we do not situate ourselves in functionalism normally, we find this argument persuasive, disturbing, and motivating.

Fundamentally, we believe "pipeline" might be a helpful concept for thinking about some kinds of group-level behaviors, and the fact that such group-level patterns can be modeled statistically can be useful in some cases. However, the number of women organized by disciplines and certainly within institutions are often not numerous enough to be investigated statistically. Therefore we propose using other methods to understand women's lived experiences that are more suited to their small numbers and that lend themselves to understanding *local* conditions – individual departments, colleges, and universities. In the next sections, we address the second of our two questions posed at the beginning of the paper: how does the metaphor help highlight or mask the lived experiences of real women working in engineering academic contexts?

How does metaphor highlight or mask certain lived experiences of women?
We pose a response to this question using data gathered from an ongoing study of the academic career pathways of women faculty members in STEM disciplines.[23]

Methods
We conducted sets of two interviews with 14 faculty members situated in science, technology, engineering, and agricultural fields that fit into NSF's categories of STEM disciplines, and including both women and men. The first interview is framed as an oral history, where the participant is asked to tell the story of her or his life, including where she or he joins the faculty at our study site. The second interview follows up on this interview using a participatory action aspect where the participant is asked about thoughts on pipeline and chilly climate theories, and what metaphors might be applicable to her or his personal career.

Specifically relevant to this paper on pipeline, we ask the following questions in our interviews:

1. "How do you feel about the pipeline metaphor and the way it explains women's underrepresentation among STEM faculty?"
2. "What aspects of women's career pathways, if any, do you feel are not covered by the pipeline and chilly climate theoretical models that should be given further attention?"
3. "How do you feel the pipeline metaphor fits or models your career path?"
4. "Reflect on the course of your career path. Are there other metaphors or ideas you feel represent your career pathway, either in place of or in addition to the pipeline and chilly climate metaphors?"
5. "I would like you to choose a metaphor that you feel best describes how you feel you fit into the working atmosphere of your department. So, for example, from my vantage point, working in my department is like – or feels like – fill in the blank."

In addition, we provided a short description of pipeline and chilly climate:

> "The idea of a pipeline models the educational system as a pipeline, with a pool of potential scientists and engineers at the input and a pool of completed scientists and engineers at the output. If there is a difference in volume, it is because people 'leaked out' along the way, and were not 'retained.' The chilly climate metaphor suggests the environment is so unpleasant that some people (particularly those already under environmental stresses) decide to leave."

A professional transcriber transcribed the interviews verbatim, editing out most crutches of speech. Interviews are then pseudonymized to protect the identities of the participants, and then the participants are invited to review the pseudonymized transcription and mention any parts they want deleted or otherwise modified to protect their identities. Because this part of the paper is based on preliminary data, we will be providing very little information about each participant here and in general not using many quotes as we are still in this process.

Data for this paper is analyzed inductively, and includes responses from both women and men. One of us made a first pass of the 14 interviews, marking sections that relate to the question of how the metaphor of pipeline masks or highlights certain lived experiences of women. Then both of us read over those sections and coded them for whether they represented highlighting or masking of different concepts, and whether they described alternative metaphors.

Results and discussion

We outline our current analysis of the stories of these 14 participants through discussion of how effective or not effective the pipeline metaphor is at understanding their lives. Each direct quote from a participant is labeled with a unique four-digit number that refers to our internal recordkeeping. In general, "[...]" is used to excerpt out interviewer interjections of understanding (such as "okay" or "uh-huh"), to excerpt out something that might identify the participant, or to otherwise improve readability.

How does the metaphor highlight particular lived experiences of women?

Many of our participants agreed that the metaphor of pipeline "sounds reasonable" (5006) both when discussing the metaphor generically, and when discussing it in relation to their own careers. For example, participant 5001 saw pipeline as "about how functional the logistics [...] and framework is for getting people through the career track they want to progress through." Participant 5008 found support in the metaphor through others' experiences, saying "I think the pipeline is a correct [metaphor]. In fact, our school did lose one at the third year review. But we also have many that made it. But we did lose one."

Participant 5003 finds the metaphor appropriate because there "is definitely a falling out of women along the way. And…and I think…I mean, that, that metaphor I think was originally brought in to explain, sort of, low numbers of women in faculty positions by saying, 'well, there was no one flowing in.' [...] So, if we don't have a steady supply, then we can't have women." However, on the heels of using the metaphor, participant 5003 goes on to say "And so, I think to some extent, it was a shifting of blame." We find this latter portion interesting as seems to imply that the pipeline metaphor masks culpability, or responsibility associated with passing through the educational process. We think there is more here to explore.

A good number of participants said they thought the pipeline worked as a metaphor because of something associated with their experience; as an example, participant 5002 said, "I think it's pretty relevant to mine because I've kind of got into the pipeline as an undergrad and have just kind of stayed through it and have had doors opened to the next phase for me along the way. So I flowed through the pipeline pretty smoothly, relatively smoothly, I had a little bit of choppiness at the postdoc, but um…" Participant 5005 said something similar, using the metaphor to be more descriptive: "Well like I said it fits well because definitely was a leak [...] It was a – a – against the flow, what you call it –[...] in some areas and as I said even if you are with the flow there is some turbulences there – [...] – that the pipe can feel – [...] and if there's a roughness in the back..." She came back to this same metaphor later, saying, "I just felt like if this (inaudible) has certain diameter [...] when it comes to time seeing where kind of hostile environment I felt like the pipeline kind of [...] the diameter. [...]And then when you [...] you feel tight, the flow changes, the smoothness changes until it opens up again [...] so I think that pipeline has some hiccups." So when pipeline is used in conjunction with other pipeline-appropriate details, this participant thinks it makes sense; this sentiment echoes Allen and Castleman's comment about the valves and bays in the pipeline from earlier in this paper.

Some people used the fact that they were still (at the time of the interviews) in STEM academic positions as evidence that the metaphor fit; for example, participant 5009 said "I think I made it to the end. [...] I really do. I'm one of the few that made it. [...] I made it to a really prestigious R1 institution in my own subfield I'm at the tip top of the mountain [...] and I'm a woman [...]— and I made it – [...] – and so you know it probably works..."

However, participant 5006 used the fact that she was still in a STEM academic position as evidence that the model *did not* work to explain her experience, saying "Well I guess it doesn't because I'm still here. Right? [Laughs] So the pipeline is, like a lot people leak out. I haven't leaked out yet. [...] I'm clinging to the pipe for dear life." She made this point twice over her interviews.

A few participants said the metaphor fit, but then in describing how it fit, demonstrated the limits of the model in describing their careers. For example, participant 5003 said "Yeah I guess it fits pretty well. So, you know, when I finished my bachelor's I had to go work. So I could have fallen out there. And I did, actually, fall out for a while I guess. And then I got an opportunity to come back." This person also made this point at two different times in the interview. So 5003 inadvertently describes one of the problems with the metaphor – that in pipeline, as Xie and Shauman argue, there is no "coming back" built in to the model (except as contamination).

It seemed however, when people indicated the metaphor fit, it fit because of an alignment with a particular defined career path either in the participants' individual experiences or in the experiences of others they knew, but not because it particularly helpfully highlighted a specific aspect of someone's career. In some ways, this makes sense: if a person is "inside the pipeline" with others, having reached the "outlet" gives an indication about the soundness of the pipeline proceeding the outlet, while, when people end up missing (who "leaked" out), we inside the pipeline cannot see what happened to them – they're just "gone;" there is nothing specific to be

able to look at. We will be following up on this idea to see if there is evidence to support it in other interviews.

In addition, we did not systematically ask participants how familiar they were with the metaphor of pipeline (or chilly climate) already before our conversation, although throughout the course of the conversation we found variation from not familiar at all to very familiar.

How does metaphor mask other lived experiences of women?
In contrast to the vagueness of the highlights, participants were very specific on many limitations of the metaphor for understanding women's careers.

Participant 5001 had a particularly specific dislike of the metaphor, saying, "generally I don't like it just because it doesn't seem to quite account for agency, it doesn't quite seem to reflect that people make decisions and choices. And it seems like it's just suggesting that people are just, you know, more like sheep [...] And they're just [...] being corralled through, instead of people making decisions and choices." She went on, "also there's a – a tendency to think of a pipeline as just being one single path, instead of multiple pathways. And then also, I don't think it, you know, really accounts for opportunities to leave and then come back, which is my experience. I more or less stayed within STEM, but I left engineering and then came back to engineering, during my undergraduate [years]." Both these points – personal agency and choice, and the multiple entries/exits – fit well with the existing critiques of pipeline.

Participant 5007 made use of particular knowledge of pipelines to point out the limitations: "Pipeline, you will never lose any particles in that line, all it loses is the energy of the (inaudible). Like, your fluid pressure in the beginning is high, and after the energy loss, the fluid pressure will become less. So that's caused – however the flow rate is the same. So that means you will never lose any members in that pipeline." Here the participant was using his knowledge of the real characteristics of pipelines to show places where the metaphor breaks down.

Participant 5014 disapproved of the negative connotations of the "leak" concept, saying, "maybe the term 'leaks' are – if there's anything that bothers me it's probably the term 'leaks' because I think there's just some family issues such as raising children or having children that [...] I mean that I think can affect the end and that's not necessarily – I don't know to me that's not like a leak..." Other participants also pointed out how family issues specifically don't seem well incorporated into the pipeline concept.

Participant 5009 pointed out that an academic career should not be the be all and end all, and invokes another common metaphor used to describe women's lives – that of balance:

> ...my sense is that why people leave is underexplored and it's – it's always as if the academic career is the valuable thing [...]I think the positiveness and the value in making choices outside of academia – I really do think that academia is sort of put on a pedestal – [...] like this is the best number one choice and it may just be the way the verbiage comes out because the focus is so much on well why don't we have more women in STEM [...] so that gets put in a real positive light you know in going off into industry is not greeted so positively. I also think the balance piece is so difficult in research environments that some people because of

> the balance piece maybe go to liberal arts institutions or comprehensive institutions to spend their careers cause the balance is just easier. It's just absolutely easier.

In this quote, we see the participant problematize the "outlet," and wrestle with the notion of "good" and "bad" careers. This same participant went on to point out that the financial considerations of employment are critical, and also highlighted the "choice" idea: "it's real tough to say no, you go into industry because you make a lot more money and that's not a dirty and awful thing. [...] Financial security for your family, for your children is a really important thing and it's a good thing to have, so I think some of those leaks get looked at in a very negative way when actually women are making positive choices."

Participant 5008 also talked about balance, saying:

> I think the thing making women in our profession to leak out is balance of work and life. And I think I mentioned it in our last interview. To be successful and – unfortunately, we always sort of forget about quality versus quantity. And we – unfortunately, there is an enormous amount of work. And I think we need to pay more attention to the quality, not just the quantity. And we have to pay attention to balance of work and life. If we just say, 'This person has,' – we keep saying the bar is getting higher and higher. That's what's happening. The bar is getting higher and higher. Is it better?

Finally, participant 5009 pointed out that sometimes individuals are not well suited to the job at the end of the pipeline. She said, "The other thing, there's stuff you have to do in an academic job that may not be the strongest skills for a person, man or a woman [...] – like teaching. [...] You know, if you don't like to teach I'm not so sure why you'd go into academia. [...] So I think there's reasons for leaving that [...] I'm not so sure the value of it gets translated correctly in that leaky pipeline." This brings up again the issue of whether choosing a different career than that set as the "successful" traversing of the pipeline should be considered "leaking out."

When asked to consider whether pipeline worked as a metaphor to describe their own personal careers, while some responses have already been discussed above, others pointed out additional limitations of the metaphor. Participant 5007 said simply, "I don't think any one of [the metaphors] fits me," and laughed. Participant 5001 again pointed to the problems of oversimplification, while participant 5008 again brought up the notion of balance (as above):

> In pipeline – well, it made no balance. I think the balance of work is terrible. So even though my wife and my relationship stayed wonderful, but my relationships with my kids, I did not spend time with them. So obviously, things suffered. But this would be, I think, important, especially for women. I'm not answering your question. But the pipeline, for me, doesn't – it doesn't affect me. I don't think those two – because I didn't leak out. And I had tenure every place. So I left because I felt I needed growth. The place where I was at did not give me the growth that I wanted to do. I think that's why I left. Every time I left is for growth, in some form or another.

Together, our participants identified many of the same shortcomings of the pipeline metaphor as did the literature described at the beginning of this paper. In short, our participants discussed

issues of value, of family, of having a balanced life, of entering and leaving the career path multiple times, and of other practical matters, all critical to thinking more holistically about faculty members' career paths.

What might be alternative metaphors to consider?

We have pointed out numerous theoretical and methodological flaws associated with pipeline, which could be summed up as the following: the pipeline is used to model the educational and employment system, but invariably as a *linear model*. However, as systems theorist Donella Meadows[24] points out, "The world is nonlinear. Trying to make it linear for our mathematical or administrative convenience is not usually a good idea even when feasible, and it is rarely feasible." (p. 111). Meadows articulates a series of system traps that we tend to slip into when we allow ourselves to pretend a system is linear, one of which in particular is germane to this discussion. She describes the trap of "policy resistance":

> When various actors try to pull a system stock toward various goals, the result can be policy resistance. Any new policy, especially if it is effective, just pulls the stock farther from the goals of other actors and produces additional resistance, with a result that no one likes, but that everyone expends considerable effort in maintaining. (p. 116).

In the case of the pipeline metaphor, we clearly hear from many voices including university and college administrators,[25] industry partners, governmental agencies,[26] and sometimes almost "design" itself [27] calling for more women to enter engineering professions in numbers proportional to their representation in the country. And yet, a large gap remains. Who are our other actors? Clearly women faculty themselves, and likely their families, their colleagues, their students, perhaps their passion for research even may serve as an actor. What is the stock over which actors are disputing? What might this new systems metaphor prompt us to consider?

We felt many of our participants were very inventive when thinking about new kinds of metaphors that might better represent their career paths. We share an expansive list from many of our participants below, few of which overlap with those above:

Participant 5001 made use of *pathways*: "I mean "pathways," itself, is a metaphor [...] and so that's the one I've tended to use, in the past [... to] talk about myself, is to talk about it as a pathway. And a pathway is wherever you can choose multiple paths [...] to pursue, and the paths will sometimes come back and merge together. And sometimes they go off in different directions. I feel like the pathway better captures just the – the way that it can be really twisty and turn – lots of different turns and whatnot, as well as this idea that there's different choices. And the choices can all be equally positive. They're just more of a decision of which one I'm gonna pursue less of that – you know, there's just less of that negative connotation [...] to any of the decisions that you make. [...] All are – all are valid decisions, just what I decide to do. So the idea that there's not a straight line, and [...] that there's multiple good choices. Just because I'm – if I decided not to stay in academia, for example, is not necessarily a bad thing."

Participant 5003 described her past as a *snowstorm*, "I think, you know, when I finished my PhD I really, I felt very despondent. I did not think that I had any worthwhile training. I didn't really feel like, I could do anything. And I didn't, I certainly didn't think I could get a faculty position

[after I received my PhD...] because, you know, a PhD basically, like, breaks you down. [Laughs...] I mean, yeah. It was a very, very tough time for me. And I, you know, I finished just, like, not feeling very positive about myself or about academia. [...] And it was another snowstorm. [Laughs.]"

She also made use of a *tightrope* metaphor: "I think, maybe, maybe mine would be like, I don't know maybe walking on a tightrope and falling off a couple of times. And getting back on. And, I still feel like, I'm on a tight rope now, but I, I feel like, the chance of me falling off is, is less. [...] And I guess by that, I-- I-- I, you know, when I was in high school I wanted to do a PhD. And then, after college that was not an option. And then, you know, some time during graduate school, I wanted-- and then, you know, I went into graduate school and got back on track. And then in graduate school I wanted to be on faculty. And then that kind of went away for a while. And then I got back on and I think now, I'm-- I'm on. But it's definitely a tight rope. In terms of… [Interviewer: Maybe a wider tight rope?] Yeah. A little bit wider and then you know, tenure. It's going to get narrower the closer I get to tenure. [...] Right now I'm not too terrified. [...] There is, there is always that tension. [...] Tenure hanging over your head."

And yet, after these two fairly negative metaphors, participant 5003 also offered the following metaphor of a *slightly oval pea in a peapod:* "I don't know. I have to say that whatever issues there are here, I…I do feel I fit in very well. […] You know, so, maybe, I would go, like, maybe, like, a slightly oval pea in a pod. Ha-ha. Because, overall, I-- I'm really happy here. [Interviewer: OK. So oval, because?] Yeah. Because it's not perfect."

Participant 5004 used a *flowing* metaphor to describe her career path: "[T]here were times where I felt like […] a river or a wind that I went against – against the flow or against the wind […] I could say that I felt like that maybe 1/3 of the time. […]The 2/3 of the time […] I felt I don't know, like something smooth. […] Not conflict. But I cannot say it was all the time feeling like going against the flow but it was not all the time that the flow was along with me."

Participant 5006 described her career as a *roller coaster*: "I guess it's like kind of a roller coaster. Because there's definitely high points when you feel really good and you feel like you're doing something that makes a difference and is really important and you feel like you totally get it. And then there are times when you have no idea what you're doing and you just want to burst out into tears or quit or whatever. But the high points have to be high enough to outweigh the low points to keep me doing it."

She also contributed a different metaphor of her department as a *box of crayons*: "OK. I'm gonna say I feel like a color in a box of crayons. Because everybody is different and everybody works on a different kind of [STEM field] and has their own points of view on things, but together we all fit in and we make a nice department. And we're very colorful."

However, participant 5006 also contributed a most extensive description of a *felt filter* in contrast with both pipeline and still other types of filters: "If it's a filter, that makes more sense. […] Filter means, right, you have certain regulation designed in your filter. Then a pool of potential engineers or scientists, [audio skip] will be examined under those regulations during a period of time and only some of them are qualified and those are the tenure[d]. Of course sometimes in the

filter, some of the good particles also get filtered out. […] Pipeline, you will never lose any particles in that line, all it loses is the energy of the (inaudible). Like, your fluid pressure in the beginning is high, and after the energy loss, the fluid pressure will become less. […] So if we have a lot of things come in, it will -- only the qualified one will going through, the rest of them will be filtered out. So that's filter. This type of filter is called a screen filter, screen filter. Yeah, there are two types of filters, the other type of filter, also functions the same way, but it has a beauty with contamination, has [the?] ability to handle continuations. Those are called felt filter. […] Felt filter, the pressure drop across the filter wouldn't be changed, even when the filter itself is contaminated. […] The fabric of (inaudible) compressed animal fibers, such as wool or (inaudible), sometimes mixed with vegetable or synthetic fibers and those kind of thing, it has capability to contain some of the (inaudible). But the pressure drop across the felted filter, will be still constant. It can maintain the same flow rate. So that might be even a better description. […] Pressure is affected, so it will take you more effort to push through that [screen] filter. […] Felt filter, you have the capability to maintain the flow rate, even though the system is contaminated. I think that should be the ideal situation. [...] I think that should be a good metaphor for you. That's the ideal situation. And how you are going to design this (inaudible) examination procedure, like a felt filter instead of screen filter."

Participant 5008 provided a really positive set of *vacation or adventure-oriented* metaphors: "Feels like working in a resort. [Laughs…] Because to me, this work is play. So coming to work is like going to a resort every day, or a cruise ship, or something. [Laughs…] When you think of it, a cruise ship is just fun. If I gave you that metaphor of cruise ship, maybe an adventure ship. […]An adventure ship, […] Well, because it's just a little bit more goals and things because a cruise ship is just fun. It is fun for me, but I also know we have things we have to accomplish. So adventure ship is better. We want to do things."

Participant 5009 described herself as an *SAT question:* "Oh I need the answer to the SAT question – which one of these does not belong? That's what I am. I damn straight guarantee ya. That is what I am. I am the answer to the SAT question. Cause I don't – I don't fit in with the rest of these guys so – […] I have a multi-dimensional life and I like it like that and my graduate students see you know all the multi-tasking that I do – I don't hide that from them –[…]-- you know I'm not real connected with any of them so yeah, I'm sort of like an SAT question."

She also offered an alternative metaphor to describe mentoring graduate students and others as like *gardening, but without water*: "The only one and I'm stealing this from a title of a symposium title that I saw at an [industry] meeting – it's like trying to grow a garden without water. [...] And they may have stolen it from somewhere else. So it's almost sort of kind of neutral. I mean maybe it's the notion that you get them out to the end of the pipeline, they're little seeds, you stick them in the ground and then you just never water them and so they never germinate, they never sink in roots and they never grow up and reach the sun. They just sit there in the ground. [...] And you can sit there in the ground and rot if you're a seed. [...] But yeah, it's tough without water."

Participant 5010 also picked up on the idea of mentoring through the metaphor of a career as a *journey*, and tried to highlight the relationship itself in the metaphor of a *travelling companion:* "Um, that whole issue of mentoring, […] I think there's the possibility of […] of a warm climate

to compete against – […] the chilly climate. […] Like they have to have someone – […] somehow getting through that journey. And it doesn't necessarily need to be someone in the same major. But, you know, but it's strongly related to whether or not someone makes it through – […] the academics process is that they have a traveling companion of some sort. And I – I mean, I think maybe it's sort of that metaphor that makes it work, right. I've known in some other places, […] groups of people who all go through the tenure process at the same time tend to form a bond – […] I mean, it lasts a lifetime. […] And I'm not sure if that metaphor has a name. But it – I mean, if I had to give it a name, it'd be like the traveling companion metaphor. […] You know, if I can just find one or two people who I can talk to, that's enough."

Participant 5014 provided two metaphors, the first as a *train*: "A train that just keeps chugging along. [...] The aspect of just steady and keeps going. Not from the aspect of running things over but [laughs...] just usually reliable, steady." However, she also provided a descriptive metaphor as being *one of the herd* in her department: "Working in my department feels like I'm a [specific herd animal] in part of a big group however you have to still do your own thing.[…] so I use that as a metaphor saying you still have to do your own thing-- you're part of a group but you're still pretty much on your own so if you don't […] get your own stuff done, nobody else is going to do it for you and you could easily perish and die. […] They're together in a group and it's like they don't really have the same overall goals – […] – but they're still individuals within that group – […] so and any given individual can either flourish or – […] or perish – […] independently of the group. But overall the group generally has – they work together as a herd and they're generally have the same goals in mind."

Finally, Participant 5016 also described an *explorer on a path*, picking up again on the themes of travel and pathways: "I would think it's kind of cliché it's more like a person in a very – it's an explorer in unknown land. [...] He has – he has an idea what he wants. He is either looking for – just looking for something [...]-- that can make him famous or something like that. [...] But he just doesn't know the path of getting there. [...] And he's exploring as I mentioned. And exploring and exploring and along the way he you know further he goes and he's further – the clearer idea what's – what's the right path to get to you know what he's – you know before he launches his exploration you know. [...] The further he goes then the further he knows and then he just try to choose a path. [...] So and sometimes it just paths out there he knows but he doesn't – there's just no way he can you know go on that route – [...] you know sometimes there's lucky explorer. He cannot just take the paths he needs to take."

After listening to participants about all these inventive metaphors, we noted something we consider startling: while participants talked fairly easily about their lives as working well with, or not, pipeline ideas and leaks, or with the idea of a "chilly climate" (another metaphor for another paper), we heard virtually no other metaphors that have been popularized to model women's careers, including the career lattice,[28] labyrinths,[29] glass ceilings[30, 31] and escalators[32] and even more.[33] We hope to explore this concept further in our subsequent work. In addition, we hear multiple "path" metaphors (a path, an explorer on a path, a journey, etc.); while we do not ascribe too much meaning to this repetition, as "pathway" is part of the study name and appears in the interview questions, we still find value in the different flavors of "path" that participants played with.

Future work

Subsequent analysis will more closely follow a discourse analysis framework outlined by Gee.[34] Gee notes that language "gets recruited "on site" to enact specific social activities and social identities" (p. 1) and provides an extensive framework to use to understand the different "building tasks of language" (p. 11), including:

1. *"Significance:* We use language to make things significant (to give them meaning or value) in certain ways, to build significance. [...]
2. *"Activities*: We use language to get recognized as engaging in a certain sort of activity, that is, to build an activity here-and-how. [...]
3. *"Identities*: We use language to get recognized as taking on a certain identity or role, that is to build an identity here-and-now. [...]
4. *"Relationships*: We use language to signal what sort of relationship we have, want to have, or are trying to have with our listener(s), reader(s), or other people, groups, or institutions about whom we are communicating; that is, we use language to build social relationships. [...]
5. *"Politics (the distribution of social goods)*: We use language to convey a perspective on the nature of the distribution of social goods, that is, to build a perspective on social goods. [...]
6. *"Connections*: We use language to render certain things connected or relevant (or not) to other things, that is, to build connections or relevance. [...]
7. *"Sign systems and knowledge*: There are communicative systems that are not language. These are all different sign systems." (p. 11)

Gee provides analytical questions for each of these building tasks, and guides us in blending the answers from a series of " 'little d' discourse (language-in-use)" statements as well as "non-language 'stuff' to enact specific identities and activities," where he then claims " 'big D' Discourses" become involved. He goes on to describe this big-D Discourse in more detail:

> When you "pull off" being a culturally specific sort of "everyday" person, a "regular" at the local bar, a certain type of African-American or Greek-Australian, a certain type of cutting-edge particle physicist or teenage heavy-metal enthusiast, a teacher or a student of a certain sort, or any of a great many other "ways of being in the world," you use language and "other stuff" – ways of acting, interacting, feeling, believing, valuing, and using various sorts of objects, symbols, tools, and technologies – to recognize yourself and others as meaning and meaningful in certain ways. In turn, you produce, reproduce, sustain, and transform a given "form of life" or Discourse. All life for all of us is just a patchwork of thoughts, words, objects, events, actions, and interactions in Discourses. (p. 7)

We see multiple places in our data where our participants engage in both little d and big D discourses. We see them struggle with what seem to be dueling (and incommensurable) identities of "competent engineering faculty member" and "good mother," through a series of linguistic tasks which interact with a larger Discourse about women and paid work (indeed, it is helpful for our purposes that Gee uses both "teacher" and "cutting-edge particle physicist" as examples in this section). We hear our participants articulate relationships with students, with colleagues, with partners and children, and with their image of their promotion and tenure committee. We see them work diligently to navigate a complicated landscape of social goods, where, Gee

explains, “social goods are anything that a group of people believes to be a source of power, status, value or worth, whether this be “street smarts,” academic intelligence, money, control, possessions, verbal abilities, “looks,” age, wisdom, knowledge, technology, literacy, morality, “common sense,” and so on [...]” (p. 2) – many of these clearly are brought to bear in scientific academic life. We hear them position particular activities as worthwhile to their career, as problematic, as critical for their family life, we hear them connect certain actions or words with significance, and invoke a variety of sign systems. All of this complexity should be brought to bear on faculty reflecting on their jobs, and is missing when we rely simply on the metaphor of pipeline to model people’s lives.

Conclusion

This paper has explored both rhetorically, through existing literature, and through empirical data the limits of using “pipeline” as a metaphor for understanding women’s careers paths in STEM academic contexts. We have particularly highlighted various critiques of the metaphor both from professional colleagues’ perspectives and from those of our participant informants.

As we said earlier, we recognize many of these critiques are not new. However, we find it important to remind the engineering education community, particularly its research community, of the theoretical and methodological limitations of relying so homogenously on a metaphor to guide our research studies.

Recognizing the place that metaphor has in our language helps us put into perspective the extent to which we no longer question the “truth” of metaphors. In this context, we believe metaphors are useful insofar as they help us see new explanations for women’s underrepresentation. From the diversity of perspectives of our own participants, we see the critical need for an ecosystem of metaphors (itself a metaphor) to consider this persistent problem of women’s low participation in engineering faculty positions. Without this ecosystem, we fear that continuous reliance on a problematic construct of mythic proportions will serve as evidence that, in fact, the engineering academic profession *does not want to become more inclusive of women,* and retains use of the problematic construct *in order that it does not become so.* However, we do not yet have so little faith in the engineering education community, and hope this paper contributes to a community-level commitment to dispense with this old myth, and embrace new thoughtful metaphors to guide our future collective research.

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