

## GENDER-BASED SOCIAL REVOLUTIONS AND THEIR EFFECT ON TECHNOLOGY EVOLUTION: A CASE STUDY OF THE SEWING MACHINE

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### ABSTRACT

*This paper applies a feminist critique of technology to develop a model for design trajectories, specifically the technology life cycle. The model aims to explain the origins of radical design changes even when scientific revolutions are absent (or distant) and radical performance improvements are inconsequential. The breast pump is introduced to illustrate how public health, social and cultural norms, federal policies, and identity influence a design trajectory. The breast pump's delayed and limited evolution despite technology advances indicates the compounding consequences of these factors on a technology's design trajectory. We then investigate the sewing machine (first patented in 1846) to explore this phenomenon more closely. Our research illustrates conditions under which a social norms lens might change the expected technological outcome predicted by purely economic or organizational models. By shifting the unit of analysis away from single designs to a trajectory of design cycles over time, this paper offers explanations for conditions under which designs will remain resistant to debiasing, with only minor incremental change, and the social dynamics associated with design discontinuities. Our model includes the social construct of gender norms as a socio-technological lens to examine the limitations of the traditional technology life cycle model. Finally, we discuss how our new model can update engineering design theory and pedagogy.*

**Keywords:** Technology Life Cycle, Design Theory, Gender, Engineering Education

### 1. INTRODUCTION

The breast pump has become an indispensable part of what it means to be a breastfeeding parent. More than 85% of breastfeeding Americans, or more than three million people, rely on the breast pump during the critical nursing stage [1]. At issue is whether the technology trajectory of the breast pump mirrors its increased necessity in society today. While breast pumps have improved from their cow-milking inspired original design – initially built as medical devices to address the problems of hypogalac-

tia or babies too weak to nurse – they remain uncomfortable, noisy, and expensive (upwards of \$1000/kit) contributing to an overwhelmingly negative user experience [2]. In a 2016 study, breast pump users reported experiencing shame, anxiety, pain, and humiliation during the pumping experience [3]. In addition, inequities to safe, affordable breast pumps, allotted time and space to pump, disproportionately affect marginalized communities across race and class [4]. Finally, the United States remains one of the few countries without guaranteed paid-family leave. This places breastfeeding Americans in an impossible situation of trying to breastfeed for 6 months or more, as recommended by the CDC, while facing the necessities of returning to work to secure more financial stability [3]. Thus, the technology trajectory of the breast pump has not kept pace with its necessity in society. And, if not, why? Despite significant scientific advancements in fluid mechanics since the first breast pump was patented in 1854 (169 years ago or nearly 6 generations of breastfeeding parents), the contemporary breast pump is still built using mature technologies, particularly the key component: an electric powered vacuum pump. The technology trajectory of the breast pump has not been determined by technology alone, but also by intersecting effects of public health, social and cultural norms, workplace and federal policies, and individual identity, all of which influence its design trajectory in direct and indirect ways [3].

The economic and social context within which the breast pump exists suggests that analyzing its design trajectory from the perspective of functionality or performance alone is unlikely to explain the conditions of its evolution, or lack of evolution. By looking closer, we could surmise that the design trajectory of the breast pump has been constrained by its priority, value, and role in a society entrenched by gender norms. For example, the male inventor of patent 949,414 “Nursing Attachment” (1909) stated (emphasis added), “The primary object of this invention is an improved construction of device for use by mothers with nursing infants, and designed particularly to avoid unpleasant and embarrassing situations in which mothers are sometimes placed

**in public places by the necessary exposure of the breast in suckling the child.”** This patent illustrates a design intent to minimize and hide the breast feeding experience—a clear message about the powerful gender norms governing priority, value, and role of women in society at the turn of the 20th century. Only in 2017, was the breast pump first designed intentionally with women’s full economic and social empowerment in-mind through the wearable breast pump, named one of “The 25 Best Inventions of 2017” [5]. The cited design uses a piezo micropump – a pump technology that has existed since the mid-1970s (patent 3,963,380). How can a widely-used device, like the breast pump, which is essential to early-human development, have failed to change for so long even though the radical performance improvement (micropump) would have predicted a technological discontinuity to galvanize its evolution?

This prompts the following question:

*What makes radical design innovation possible when technology is not a constraint and the meaning more or less remains the same [6]?*

This research attempts to answer this question by re-examining the structural analyses of the technology trajectory of an engineered product. The goal of this paper is to explore the limits of existing technology life cycle models which currently do not factor in social constructions like gender. As this paper will show, neither new technology nor change in social meaning can summarize with high precision the trajectory of highly gendered devices, such as the breast pump (or the sewing machine, which this research will examine). This paper analyzes the sewing machine instead of the breast pump due to the order of magnitude difference in the number of patents (innovations) associated with the sewing machine compared to the breast pump. A case study of the sewing machine gives rise to a new model, where radical changes in design are analyzed as driven by substantial social change. Using gender as a construct subject to social norms, the paper contributes a new model for the technology life cycle. This new model accounts for social change as an explicit source of variation to the solution principles for a design throughout the various stages of a technology life cycle.

### 1.1 Background & Motivation

Technology [9] and design roadmapping [10] are approaches used to plan the long-term development of the features, functionality, and user experience of a product. These approaches are predicated on evolutionary models of technical change [11]. The technology life cycle (TLC) and S-curve pattern of innovation-like models are highly influential evolutionary models of technical change. These models theorize the continuous and then discontinuous change in product performance over time and have been shown to have good empirical accuracy across a number of technologies [12].

In this work, we focus on the evolutionary TLC model. This model depicts technological progress in an industry through four stages: an era of ferment, a dominant design, an era of incremental change, and a technological discontinuity, which reinitiates a new era of ferment (Figure 1). This theoretical model focuses on capitalizable performance, such as manufacturing cost

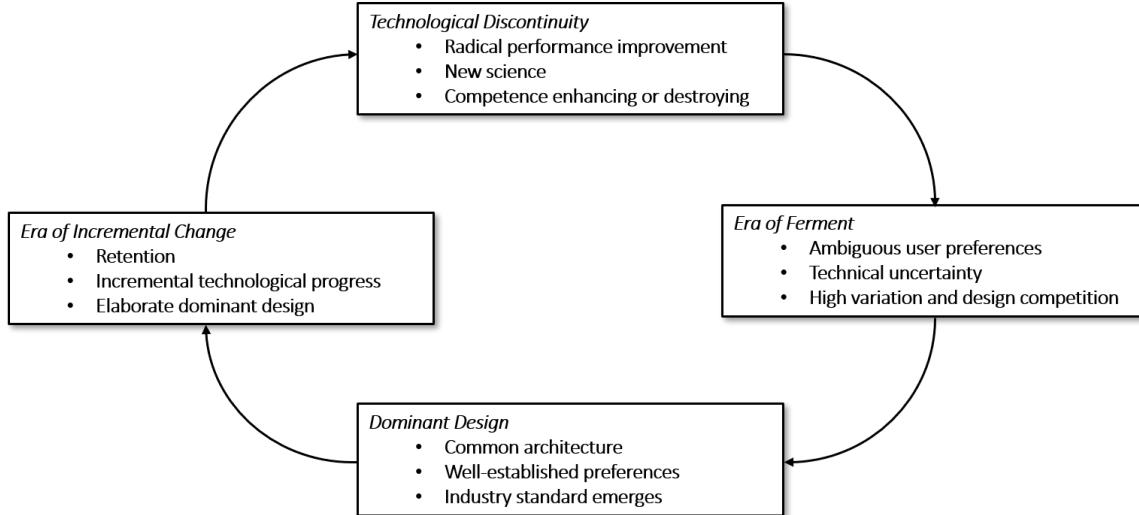
and accruable value, as the observable and measurable changes to a product. In the view of the TLC model, innovation takes place when technology improves, led by firms investing in the underlying research and development that drives technology improvement [7]. Innovations then succeed when the performance improvement exceeds the cost customers are willing to pay for the improvement.

While new science and radical technological improvement are drivers of product evolution, the current TLC model does not account for social changes, e.g. evolving gender roles and expectations, as sources of variation in technology evolution [7]. This oversight has resulted in inconsistencies in predictions with respect to radical innovations. The history of the sewing machine is one exemplar.

Rioting tailors, dramatic patent lawsuits, women’s labor movements, wars, and an industrial revolution (to name a few) all surrounded one of the 19th century’s greatest inventions: the sewing machine. The sewing machine, which evolved from bone and needle thousands of years ago, not only transformed the garment manufacturing industry, it ushered in a new era and class of what was considered “women’s work”. The rise of the sewing machine as an essential commodity in both the home and industrial spheres can be explained from both economic and organizational frameworks, like the TLC model, but found that these frameworks provide an inconsistent understanding into sewing machine innovation. For example, while the TLC model is correct in predicting the eventual appearance of a dominant design for a sewing machine, the model is unable to predict which users’ preferences will drive the next era of ferment. This is because the TLC model cannot interpret whether the ‘users’ are the authors of the preference or whether ambiguous preferences are the result of shifting expectations for women’s behaviors – and therefore preferences are simply enactments of established norms. Historically analyzing the design transformations of the sewing machine through the lens of gender norms will provide a critical lens to view technological progress through fundamental shifts in the cultural and political landscape.

### 1.2 A Social Norms Model of Technology Trajectories

In the following sections, we develop our social norms model of technology trajectories building upon prior research in economical, organizational, design, and techno-feminist studies. This model is grounded in a feminist critique of technology that explicitly accounts for how social constructs, like the gender system, affect a technology life cycle. We have chosen a feminist critique because, in any society, “gender is one of the chief axes along which inequalities of power are organized” [13, p. 1]. This means that gender-based social revolutions have the power to initiate technological discontinuity, which may free a technology trajectory from its era of incremental change and dominant design. The feminist perspective on technology makes the claim that no technology is neutral in its purpose or existence. Rather, technology is a form of social knowledge that reflects a society’s practices, possibilities, and social hierarchies [14]. To illustrate our model, we will provide a technical-historical analysis of sewing machines sampled from over one hundred years of sewing machine design patents. This analysis will illustrate



**FIGURE 1: THE TECHNOLOGY LIFE CYCLE,  
ADAPTED FROM TUSHMAN & ROSENKOPF [7], KAPLAN & TRIPSAS [8]**

the contributions of a social norms-based technological life cycle model in describing and predicting technology evolution. Similar to Kaplan et. al [8], we apply the model to each stage of the TLC to illustrate the predictions that our model makes about the life cycle of the sewing machine. Finally, we conclude with how this model can advance design theory and engineering education pedagogy.

## 2. THEORY

### 2.1 Integrating a feminist perspective into technology life cycle theory

Although it is widely recognized that there are, and can be, different contextual origins of inventive activity, technology life cycle theory is still often framed through economic and organizational perspectives [8, 15]. As such, social context, or any further critique of socio-cognitive factors in technological trajectories have, for the most part, been neglected or acknowledged as being relevant but then otherwise ignored. Kaplan et al. [8] questioned this narrative by suggesting that cognitive factors are essential to understanding the dynamics of technology evolution. Their cognitive-informed model describes technological change as involving interaction between multiple actors/users/producers and their environment. This interaction itself depends upon the history of a technology (for example, the maturity of the core components [16]) and the social context (such as network effects [17]). Eventually, the interaction generates a technological frame – the economic and organizational perspectives the actors have about the technology. Technological frames capture how actors make sense of a technology [8, 18]. Technological frames structure the social context that gives rise to specific economic and organizational actions [19].

While Kaplan's model makes important steps toward acknowledging the social context of technology, Kaplan's and all other current technology life cycle models make key assumptions on:

1. the definition of what technology is;

2. the role and significance (effect size) of social context in technological trajectories; and,
3. the autonomy of preferences.

In this paper, we apply feminist critique to re-examine these assumptions that form the underpinnings of technology life cycle theory. We investigate familiar TLC-related questions: Where does technical variation originate? Under what conditions does a dominant design emerge (or not)? What determines which design will become dominant? When does technological discontinuity occur? We apply a feminist lens to construct a new model for technology trajectories that addresses these key questions at each stage of the cycle. We use gender as a framework to examine femininity and masculinity among individual identities, and provide language to describe social and cultural constructions of power that reinforce those understandings [20, 21]. We then illustrate an application of the model through an analysis the sewing machine.

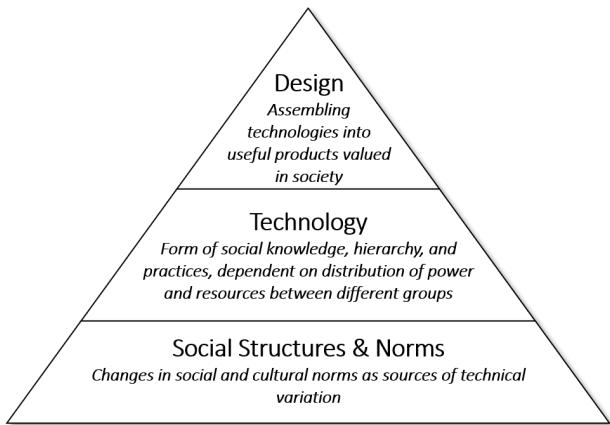
The following subsections outline the theoretical foundations for this social norms framework for technology evolution.

### 2.2 Defining Technology and Technological Frames

A central question in the concept of a technology life cycle is the very definition of technology. When applying a critical feminist lens to technology life cycle theory, the definition for “technology” can be expanded to a more contextually-aware definition. Building off of gender technology scholar Judy Wajcman's [22] definition, we define “technology” as a form of social knowledge, practices, and products. It is the result of conflicts and compromises, the outcomes of which depend primarily on the distribution of power and resources between different groups in society. Therefore, a design, which is an assemblage of one or more technologies, consists not only of a final device or system, but also a social process that occurs between the user, the artefact, and society [23]. Defining technology in this way makes explicit the intertwining of technological and social processes.

Given the integral relationship between a technology and the social processes within which the technology is developed and deployed, designs embodying those technologies are better understood as social objects [24] paired with intention-bearing functions rather than physical objects with intention-bearing functions. If a "design embodies knowledge needed to produce a technological device or system" [19], then changes in a design reflect the knowledge *and* social changes within the society in which a device or system exists. This concept is illustrated in Fig. 2). At the base of the pyramid is social structures and norms. Changes in social norms drive technologies. Lastly, the available technologies then determine the range of possibilities for a design.

Social inequalities in technologies are one of the most prominent examples of the effect of social context on technological development. Since the Industrial Revolution, the word "technology" itself was viewed as progressive, fueling the techno-Utopian hype that pedestalized improvements in power, efficiency, and rationality as ends in themselves. The dominant myth that technology represented both technological and social progress obscured the reality that mere technological development did not mean social improvement for everyone [25].



**FIGURE 2: SOCIAL NORMS CENTERED EPISTEMOLOGY OF DESIGN**

Defining technology through a feminist perspective enables a technology life cycle to take into account how social context is an indissociable part of technology development. Social structures can and have changed. If so, it can be concluded that social discontinuities are (also, alongside radical technological improvement and new science) drivers of technological discontinuities and technological improvements. We therefore add social revolution or disruption of social norms as an explicit force in technological discontinuities, as shown in the top box of Figure 6.

### 2.3 The Gender Value System & Technology Life Cycle

In the prior section, we argued that social context can play a disruptive role in a technology life cycle. In this section, we apply feminist theory to understanding the effect of social context on what is characterized as 'incremental change' in a technology life cycle. To understand the effect of social context on incremen-

tal change, it is important to define the gender-value system as a social construct. Gender researchers use the term *gender-value system* to describe the power structure (norm) that organizes the relationship between sexes on a symbolic, structural, and individual level [26]. "Gender as a principle of classifying human beings is a universal, all-pervasive characteristic of society, in fact so much so that referring to human beings obscures the fact that they are always perceived as gendered. Consequently, history is understood as a series of events shaped by groups of gendered beings over time" [13, p. 1]. The system is built according to principles of separation and hierarchy: the principle of separation means behaviors and tasks are divided into male-masculine and female-feminine domains; the principle of hierarchy considers the male-masculine being as the true standard in society and superior to that of the feminized being. The gender value system leads to role expectations and, by extension, expectations on the subjective preferences one might have given their expected roles [26].

The gender-value system's principles of hierarchy and separation can be traced back to reveal its influence on the design and engineering of technology, and inherently, technology life cycles. In a critical experiment on the effect of role expectations on subjective preferences, Ehrnberger et al. [23] demonstrated how gender norms manifest in a design's product language, form, and functionality. The researchers swapped the product language and aesthetic codes of two common household products perceived as traditionally 'masculine' and 'feminine': the handheld power drill and handheld blender, respectively. Functionally, the two products are nearly identical. Both have a motor to rotate a component (i.e., a drill bit or a whisk), thus transforming electrical energy into mechanical rotational energy. The researchers applied gender-value systems principles to each product to create new prototypes: a 'masculine' handheld blender and a 'feminine' power drill. Exhibition showcases around the world confirmed the hypotheses that gender and technology researchers have been studying for decades: *people infer the function of a product by its gender encoding more so than by its perceived function*. In the experiment, the researchers swapped the product language for a power drill and a hand blender, as shown in Figure 3, in the design for a new power drill, as shown in Figure 4. They argued that the (original) power drill embodied the product language of a masculine device whereas the hand blender embodied the product language of a feminine device. The manufacturers' choice of product language reflected beliefs about 'male' and 'female' technology, i.e., the gender-value system. Participants in the exhibitions had difficulty discerning that the drill shown in the left side of Figure 4 was a drill at all because of its feminine design and product language. In contrast, they were able to discern the purpose of the 'masculine' hand blender – and also associated its design with being "tough". Describing the 'masculine' hand blender as "tough" is a manifestation of the gender-value system's principle of hierarchy.

While the products designed by Ehrnberger et al. [23] were entirely fictitious, commercial products embody exactly the principles they tested. The power drills marketed by WorkPro, shown in Figure 5 illustrate the gender-value system at play with the pink-colored power drill for women and the "tough" power drill



**FIGURE 3:** POWER DRILL FROM BOSCH (LEFT) AND HAND-BLENDER FROM BRAUN (RIGHT). REPRINTED FROM EHRNBERGER ET AL. (2012) [23]

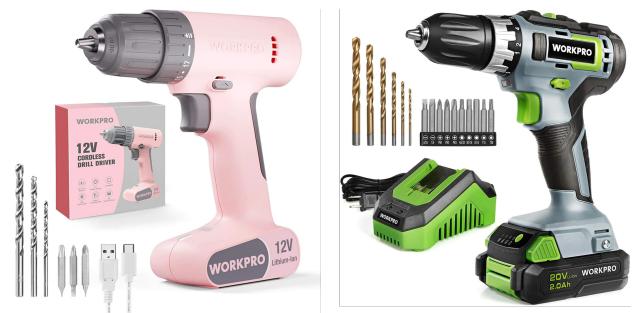


**FIGURE 4:** THE DRILL "DOLPHIA" (LEFT) AND THE MIXER "MEGA HURRICANE" (RIGHT). REPRINTED FROM EHRNBERGER ET AL. (2012) [23]

for men [27]. From consumer electronics to hygiene products, gender-biased designs are everywhere. The message is hard to miss: masculine products are often perceived to be more valued, function and feature-driven, and performance oriented; feminine products are perceived as more decorative and simplistic, with limited functionality, and thus less valuable and capable [23]. This striking division and hierarchy in product design reinforces the principle that people are assigned into roles based upon gender norms [28]. But, expectations about gender roles can change. Changing gender roles and expectations can influence the preferences individuals display. Women can, for example, have subjective preferences for “tough” power drills – but this is only socially acceptable after a social revolution that permitted women to work in traditionally male-dominated roles. However, during social change, subjective preferences can be ambiguous because the end-result of the social change is not yet clear. The effect of changing gender roles and expectations is therefore reflected in the era of social change box of the social norms model of Figure 6.

#### 2.4 Reassessing the Autonomy of Preferences

In the two previous sections, we argued that social disruption can cause a technological discontinuity. Once this discontinuity occurs, changing expectations in the gender-value system create ambiguity over the preferences that individuals may have since the assumptions of preferences, given the prior gender-value system, no longer hold. In this section, we apply a feminist critique to reassess how preferences shape the emergence of a dominant design. More specifically we focus on the TLC cycle’s interpretation



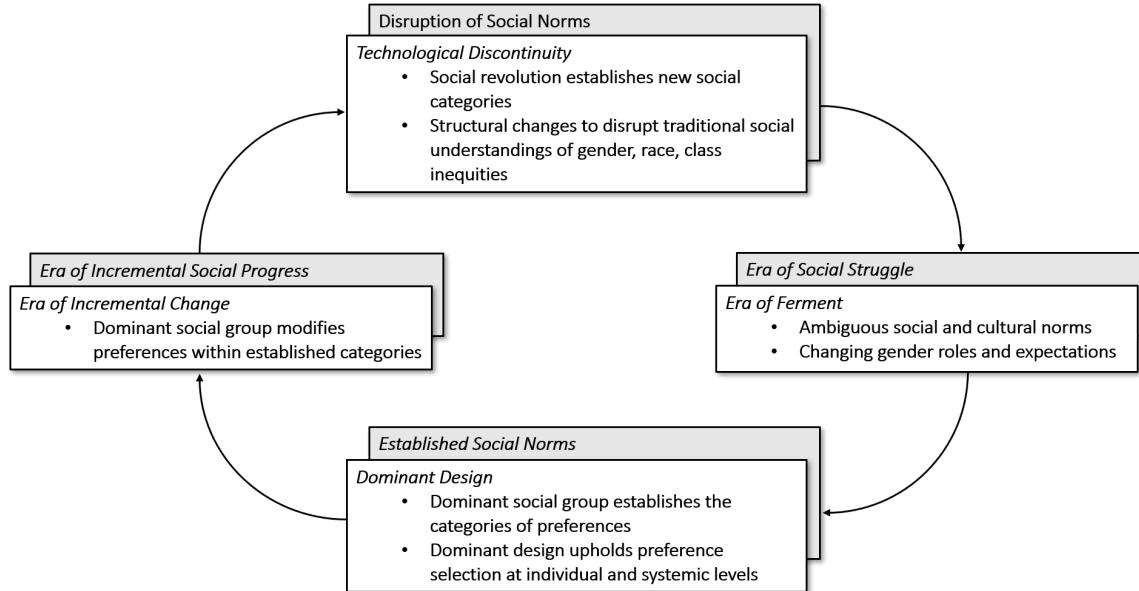
**FIGURE 5:** 2023 POWER DRILLS FROM WORKPRO [27]

of a dominant design, which is characterized by a common architecture and embodiment of “well-established preferences” [29].

Scholars studying the TLC acknowledge the complex process in which a dominant design emerges that involves various non-technical factors such as competing coalitions and communities that span from public and private sectors [30]. Organizational and technological explanations theorize that manufacturers will settle upon a dominant design [11] based upon organizational and technological factors such as the stability of the core components of the design [16] and the number of competitors [17], respectively. Kaplan [8], Garud & Rappa [31], Orlikowski [32] and others understood the co-constitutive nature of technology, or the concept that technology shapes users and users shape technology. Across all product categories, it is rarely the economically or socially weak whose ideas shape products [33]. The most influential users will shape the dominant design and their preferences will become the preferences embodied in the dominant design.

At issue, therefore, is whose preferences become the “well-established preference”. For example, when motor vehicle systems are designed based on the male norm, it was found that women are 17 percent more likely than men to die in a car crash and 73 percent more likely to be seriously injured [34] [35]. Why? Seat belts, airbags, and car crash test dummies were historically all modeled on men [36]. This example of many, shows that it is often the powerful social groups whose preferences are represented in the dominant design. In the social norms model, a dominant design emerges when a powerful social group exerts its influence to codify both the categories of preferences and the preferences in a design. Afterwards, non-dominant groups can modify preferences but not usually the category of preferences.

In summary, social context is an important driver in a technology life cycle. Social disruption can cause a technological disruption. After the social disruption, subjective preferences can be ambiguous as the expectations of social roles change in the gender-value system. Eventually, a powerful group can exert its preferences on a product, causing the emergence of a dominant design with those dominant preferences embodied. Less powerful groups can modify dominant design slightly and incrementally, but the design is otherwise stable because the category of preferences remain stable. Eventually, another social disruption can cause a new discontinuity to occur. These ideas are summarized in Figure 6.



**FIGURE 6: OUR SOCIAL NORMS MODEL OF TECHNOLOGY LIFE CYCLES**

### 3. METHODOLOGY

We apply our social norms theory of technology trajectories to the historical development of the sewing machine and reinterpret the four stages of the TLC model: an era of ferment (variation), a dominant design (selection), an era of incremental change (retention), and a technological discontinuity, which initiates a new era of ferment [29]. For each stage of this cycle we identify social mechanisms contributing to the emergence of a dominant design, changes in solution principles, and rate and direction of technological change during periods of incremental progress [8].

Since a technology life-cycle takes place over decades, and in order to observe an innovation's emergence and stabilization, we used the case method to study the design trajectory of the sewing machine and selected relevant patents to analyze [38]. Given the significant number of innovations since the first sewing machines were built 200 years ago, we down-selected from hundreds of patents to find ones that showed novel physical and functional architecture [39]. We used these patents (see Figure 7) to ground theoretical development on the effect of social norms on a technology life-cycle rather than trace every innovation associated with the sewing machine or even to trace a performance improvement. This reinterpretation will take place through two existing models of a technology life-cycle – the classic TLC model [7], Kaplan's technology frames model [8] – and the social norms model developed previously in the Theory section.

### 4. RESULTS & DISCUSSION

This section presents the application of the social norms models we developed, including our reconstructed TLC cycle (see Figure 6), on the history of the technology life cycle of the sewing machine. We also weave historical context surrounding sewing machine design to explain each stage of our social-norms TLC.

Table 8 summarizes the findings about the technology life cycle of the sewing machine based upon the social norms model of technological trajectories. The following sections elaborate the findings summarized in this table.

#### 4.1 Era of Ferment

While technical variation is often at its highest during the era of ferment, the underlying origins of technical variation are undertheorized from economic and organizational perspectives [8]. A historical study using gender as an analytical lens reveals a politically and socially fraught landscape surrounding sewing machine invention pre-1850s, which we reinterpret as an 'era of social struggle'. We hypothesize that ambiguous social and cultural norms, specifically changing gender roles and expectations, may have contributed to high variation in architecture and aesthetic during this period. An unprecedented influx of women entered the labor market (in part due to the Industrial Revolution) restructuring what was considered "women's work"; this consequentially gave rise to sexual and class divisions of labor [13]. Sewing machines built during this phase, (see Figure 7) may have reflected this social ambiguity. Machines A-F from Figure 7 embody more traditionally masculine characteristics and form representative of the era – they were constructed of wood or cast iron, rugged and heavy. By the 1850s, more than 75% of sewing machines built were used in manufacturing processes [40]. However by the end of the 1850s, sewing machine manufacturers tapped into the domestic market and produced more lighter weight, artistically attractive machines for the home. Patents 9,041 and 14,956 (labels F and G, respectively, see Figure 7) represent the sewing machine's transition towards becoming a highly desirable consumer product for women, one that is portable and aesthetically pleasing enough to enhance the home.

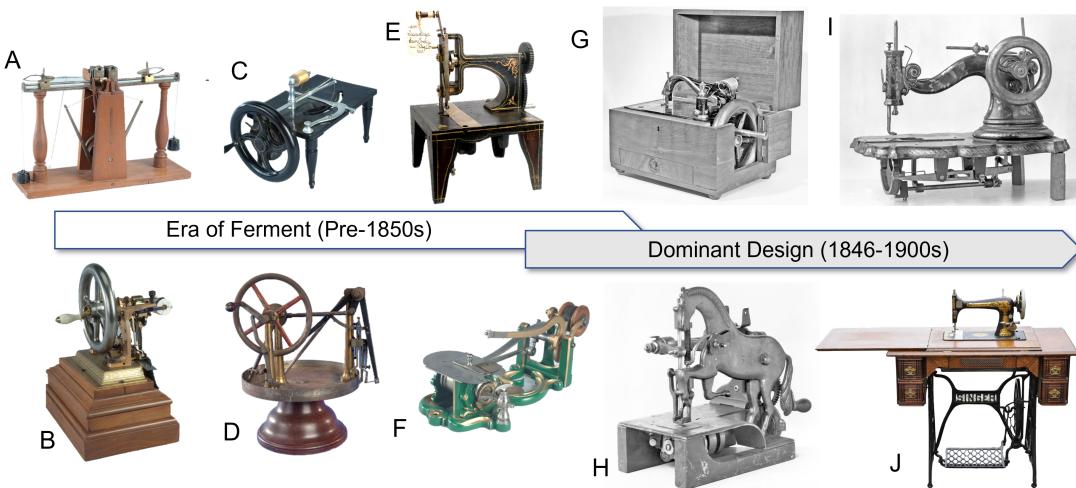


Table of select sewing machine patents

Patent	Author	Year
A 2,466	Greenough	1842
B 4,750	Howe	1846
C 7,776	Wilson	1850
D 7,824	Robinson	1850
E 8,294	Singer	1851
F 9,041	Wilson	1852
G 14,956	Grover	1856
H 22,148	Perry	1858
I 44,063	Atwater	1864
J 464,277	Singer	1891

FIGURE 7: SEWING MACHINE EVOLUTION: ERA OF FERMENT TO DOMINANT DESIGN [37]

#### 4.2 Emergence of a Dominant Design

While the traditional TLC is correct in predicting the sewing machine's dominant design eradicating to its more inexpensive selling price, this only partially explains its emergence. Similar to Kaplan, we examined how actors (sewing machine inventors and buyers) used social mechanisms to position their preferred design to win. Most notably, I.M Singer patented the first commercially successful sewing machine (patent 8,294 in 1851) and aggressively marketed the sewing machine on national and international platforms to help overcome the public's initial suspicion of sewing machines [40]. The Singer Company hosted elaborate exhibitions where often young, attractive white women were showcased sewing in these exhibits, creating imagery and association around the gender identity and social status of those who sew.

Applying a social norms perspective, the sewing machine's dominant design might also be explained by how a dominant social group established the categories of preferences – such as the shape of the machine, the material finish, and overall product language surrounding the machine. In addition, the establishment of the Sewing-Machine Combination from 1856 to 1877 allowed four sewing machine manufacturers to hold monopoly over essential machine design patents, which may have crowded out other innovations and helped monopolize on a dominant design [40]. Patents 22,148, 44,063, and 464,277 (labels H, I, J respectively, see Figure 7) represent changing styles (and perceptions) of sewing machine design that appeal to the more traditional feminine aesthetic – from a horse inspired design to machines that became more detailed and beautifully ornate. This led us to re-labeling the era of dominant design to “established social norms”. At this point, sewing machine design and association with femininity and woman's work was solidified, thus fixing the categories of preferences for users at individual and systemic levels.

#### 4.3 Era of Incremental Change

The era of incremental change is portrayed in literature as a period of inertia in which the dominant design is difficult to dis-

place and technological improvements are minor, as constrained by the dominant design [8] [7]. During this era, dominant and weaker social groups may modify preferences within established categories. For example, while improvements to automation of the sewing machine are observed, most innovations, as discovered from our patent analysis, focused on packaging, material selection, automation, and form factor, as shown in Figure 9. From the 1900s to present, sewing machine design and functionality have remained largely unchanged. Notably absent are patents associated with physical ergonomics or worker safety. A 2020 study in India reported that 88% of sewing machine workers experienced moderate to severe musculoskeletal disorders, namely lower back and neck pain, for more than 12 months because of the harmful work posture imposed when using the sewing machine for long hours [41].

#### 4.4 Technological Discontinuity

We argue the mechanism to initiate a technological discontinuity arises from a social revolution that establishes new social categories, i.e structural changes that break traditional social and cultural norms surrounding gender roles and expectations.

The hypothesis developed by this work is that gender provides an explanatory variable in design trajectories – and therefore should not and cannot be ignored. The consequences of overlooking gender norms in technological development can be traced back to the introduction of labor-saving devices and the subtle sexism of household technologies. For more than a century, technology companies advertised and promoted a new class of ‘labor-saving devices’ – i.e the sewing machine, dishwasher, and washer and dryer, etc – as technologies that increased productivity and saved time. While these machines did help liberate majority middle-class women from the drudgery of the certain technical, time and energy consuming tasks, numerous studies discovered that household technology innovations did not notably reduce the number of hours women spent doing housework; in fact, women spent *as much or more* time doing housework [42]. Labor-saving devices did not, themselves, change the norm that housework is

	Era of Ferment	Dominant Design	Era of Incremental Change	Discontinuity
Technological outcomes to be explained	<ul style="list-style-type: none"> <li>Greater or lesser variation takes place</li> <li>Specific variants are introduced</li> <li>Ambiguous user preferences</li> </ul>	<ul style="list-style-type: none"> <li>A dominant design is achieved or not</li> <li>A particular technology becomes the dominant design over others</li> <li>Well-established preferences</li> </ul>	<ul style="list-style-type: none"> <li>Inertia develops around the dominant design</li> <li>Incremental technological progress</li> </ul>	<ul style="list-style-type: none"> <li>A new technology emerges or not</li> <li>Radical performance improvement</li> <li>New science</li> </ul>
Technology life cycle questions	<ul style="list-style-type: none"> <li>Where does technical variation originate?</li> </ul>	<ul style="list-style-type: none"> <li>Under what conditions does a dominant design emerge (or not)?</li> </ul>	<ul style="list-style-type: none"> <li>What determines which design will become dominant?</li> </ul>	<ul style="list-style-type: none"> <li>When does technological discontinuity occur?</li> </ul>
Social norms perspective (our model)	<p>Mechanism:</p> <ul style="list-style-type: none"> <li>Technical variation is driven by:</li> <li>Ambiguous social and cultural norms</li> <li>Changing gender expectations</li> </ul>	<p>Mechanism:</p> <ul style="list-style-type: none"> <li>Dominant social group establishes the categories of preferences</li> <li>Dominant design upholds preference selection at individual and systemic levels</li> </ul>	<p>Mechanism:</p> <ul style="list-style-type: none"> <li>Dominant and weaker social groups modify preferences within established categories</li> </ul>	<p>Mechanism:</p> <ul style="list-style-type: none"> <li>Social revolution establishes new categories</li> <li>Structural changes that break traditional social understandings of gender, race, class inequities</li> </ul>
Case study: the sewing machine	<ul style="list-style-type: none"> <li>High variation in architecture and aesthetic</li> <li>Highest influx of women enter labor market to work in garment factories</li> <li>Rise of sexual and class division of labor surrounding who sews</li> <li>Male inventors motivated by idiosyncratic factors to design sewing machine</li> </ul>	<ul style="list-style-type: none"> <li>Various male inventors impose gender-value system ideals about sewing as “women’s work”</li> <li>Aggressive marketing efforts establish sewing machine as labor saving devices for women and girls</li> <li>Influx of inexpensive machines makes sewing machine a highly desirable consumer product</li> </ul>	<ul style="list-style-type: none"> <li>Incremental shifts in role and status of women in society and women’s work</li> <li>Minor improvement in functionality, innovations focus on packaging, material selection, aesthetic</li> <li>Minor shifts towards improving safety and ergonomics of sewing machine</li> </ul>	<ul style="list-style-type: none"> <li>To be determined</li> </ul>
Timeline	<ul style="list-style-type: none"> <li>Pre-1850s</li> </ul>	<ul style="list-style-type: none"> <li>1850s – 1900s</li> </ul>	<ul style="list-style-type: none"> <li>1900s – Present</li> </ul>	<ul style="list-style-type: none"> <li>To be determined</li> </ul>

FIGURE 8: SOCIAL NORMS MODEL OF TECHNOLOGY LIFE CYCLE

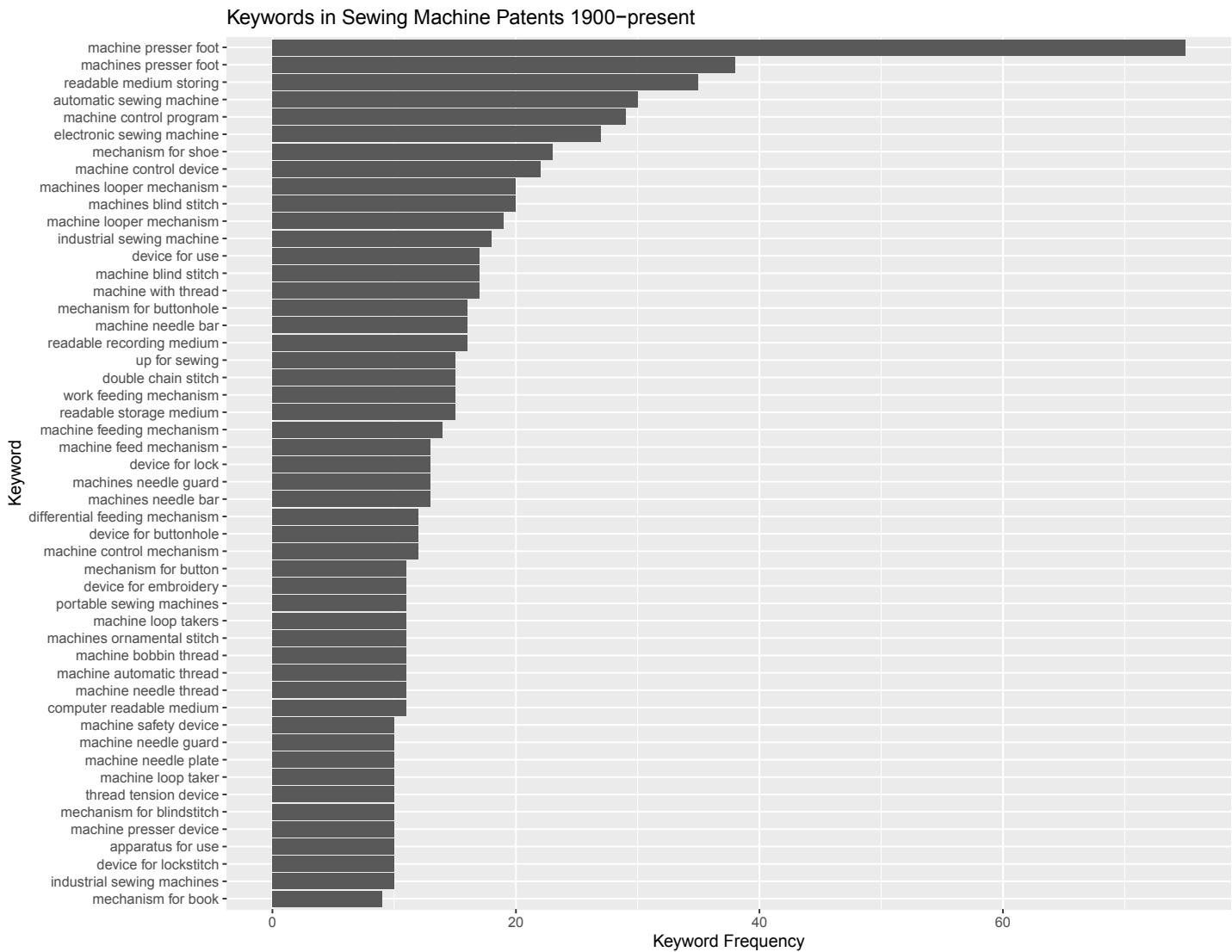


FIGURE 9: NUMBER OF PATENTS IMPLEMENTING KEY FUNCTIONAL INNOVATIONS [39]

still, largely, “women’s work”. If innovations should meet a market or societal demand, which consists of gendered individuals, our claim is that an explicit consideration of gender must play a pivotal role in both designing but also in a structural analysis of technological change.

#### 4.5 Implications for Design Theory & Engineering Education

An overarching goal of this paper (and future work) is to help equip engineering educators, students, and practitioners with design theory that reflects the increasingly interconnected social and technical challenges our society faces today. Pedagogy situated in accessible real-world artefacts, like the sewing machine, is shown to be more inclusive and engaging, especially for minoritized students in engineering [43]. Our inductive analysis of the sewing machine and new social norms based model for technological trajectories represents a historically significant example and framework for students, educators, and practitioners alike to see how social context cannot be separated from the technical

or the practice of their profession. This challenges engineering culture’s tendency to decontextualize theory and practice, which frames social justice issues such that they seem irrelevant to engineering education and practice [44]. Based on this work, we aim to create modular lesson plans to provide the resources and scaffolding engineering educators need to more easily and effectively implement principles of feminist pedagogy and design justice [14] into their curriculum to help create design practitioners who account for justice and equity as fundamental components of the engineering design process [45].

This work offers an update to current design innovation theory that directly addresses the long-standing question of why designs, for example highly-gendered technologies, remain resistant to debiasing by shifting the unit of analysis away from single designs to a trajectory of design cycles over time. We expand the epistemic scope of technology life cycle theory to acknowledge how social norms, like the gender system, drives and/or constrains technology development in often inequitable ways. This work adds to growing discourse that questions and reassesses

the relationship between design and power [14]—namely, who do we design for and with, who gets to design, and what values do we encode and reproduce in the technologies we design?

## 5. CONCLUSION

Our research aims to explain the conditions under which a social norms lens might change the expected technological outcome predicted by purely economic or organizational models. We applied a feminist critique to re-examine the underlying assumptions of the TLC including (1) the definition of what technology is (2) the role and significance (effect size) of social context in technological trajectories and (3) the autonomy of preferences. Incorporating gender into TLC theory radically challenges long-standing engineering design epistemology around core concepts such as technology and subjective preferences. In sum, we argue that social revolutions, for example the creative destruction of gender roles and expectations, are as important as scientific advances in fomenting significant technical change (see Figure 6).

We began with attempting to answer the following question: *What makes radical design innovation possible when technology is not a constraint?* To answer this question, we looked at the breast pump and sewing machine to help develop a social norms model of a technology life cycle grounded on Kaplan's technological frames model [8] and feminist critique of technology. We then studied the design trajectory of the sewing machine to demonstrate application of the model.

Further research will explore how the feminized identity of an engineered product influences its innovation trajectory and design transformation dynamics. We will investigate the causal effect of gender as an explanatory variable in the structures of solution principles in engineered products, and subsequently, their design trajectories and life cycles. This research will enable an empirical and in-depth theoretical understanding of the extent to which gender norms influence design parameters such as function, form, obsolescence, and sociotechnical significance.

This paper does not aspire to provide a general philosophy of technical change. Rather, it attempts to focus on questions that provoke a re-imagining of technological development outside gender and capitalistic norms. In summary, this paper claims that social revolutions provoke technological development and that social revolutions are at least as significant as radical science as original determinants in design trajectories.

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