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The future of manufacturing: Utopia or dystopia?

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Abstract

Digital manufacturing technologies (DMTs) have the potential to transform industry productivity, but their introduction into the workplace is often a complex process, requiring not only technical expertise but also an awareness of ethical and societal challenges surrounding human–system integration. Concerns about the introduction of new technology have been prevalent throughout history, and exploring public perceptions of these technologies can provide insight to help address such cultural anxieties. However, evaluating user perceptions of futuristic technology is difficult, requiring novel approaches to provide context and understanding. To explore users' perceptions of future DMTs, we applied the ContraVision technique in a questionnaire-based study. Participants viewed films, representing fictionalized utopic and dystopic visions of what the future of these DMTs might involve, and a questionnaire probed the perceptions of the technologies afterward. Findings showed that irrespective of the way technology was portrayed, participants had concerns about the ethical and responsible implementation of these tools. Participant responses were analyzed to identify key challenges for policy surrounding DMT implementation in the future of manufacturing.

KEYWORDS

ContraVision technique, digital manufacturing, ethics, Industry 4.0, public perceptions

1 | INTRODUCTION

In a concept known as Industry 4.0, advances in digital technology are creating new opportunities to improve productivity within the manufacturing industry (Pereira & Romero, 2017). Digital manufacturing technologies (DMTs) found within Industry 4.0 utilize information and communications technologies to support data-driven decision-making and performance. These include systems such as industrial Internet of Things (IoT) technologies (Asplund & Nadjm-Tehrani, 2016; Sisinni et al., 2018), automation and robotics (Javaid et al., 2021), virtual and augmented reality (Ariansyah et al., 2022; Erkoyuncu et al., 2017), and human physiological sensing (Argyle et al., 2021; Ariansyah et al., 2020). Industry 4.0 has the potential to transform manufacturing; however, as found in historical accounts of eras involving major technological change, effective integration relies on a design paradigm that considers the human-centered impacts of the new systems (Autor, 2015). Although DMTs have many potential benefits toward improving organizational productivity, system flexibility, increased product quality, and reduced environmental impact, it is recognized that significant challenges surround their implementation, for example, relating to addressing worker and societal concerns, the requirement for highly trained users, and cyber security risks (Sony, 2020). Research is needed to identify societal concerns involving the risks created by such systems, and neglecting this may limit successful technology implementation programs and lead to the failure of sound technological solutions (Morgan, 1997). In this study, we investigate public perceptions and attitudes toward DMTs through the demonstration of a novel design fiction method, the ContraVision technique (Mancini et al., 2010), with a view toward identifying challenges and opportunities for the design of future manufacturing systems.

In the present state of manufacturing, considerable research has focused on identifying barriers and enablers to Industry 4.0 adoption. At the organizational level, barriers to Industry 4.0 readiness include legislative limitations or lack of standards, management issues, and a lack of workers with knowledge or experience with Industry 4.0 technologies (Stentoft et al., 2019). Successful implementation of DMTs such as distributed data technologies requires internal management of such systems to be at low cost and at a scale manageable with organizational resources (Maple, 2017). Challenges also exist around developing standardized protocols for technology implementation, for example, to ensure the security of IoT data in mobile versus nonmobile systems (Maple, 2017). At the individual level, perceptions and attitudes toward DMTs play a significant role; perceptions of artificial intelligence (AI) technologies are a significant factor in the adoption of such technologies (Bitkina et al., 2020). In terms of enablers of DMTs, communications on potential impacts of new technology may benefit from a user-centered approach, customized to target audiences (Morris et al., 2005), and focusing on specific applications rather than general use (Castell et al., 2014). Castell et al. (2014) surveyed the British public on attitudes toward science and technology, with a particular focus on the use of robotics across several domains. While 89% of the respondents stated that they had some familiarity with the use of robotics in manufacturing, the authors identified an effect of context on attitudes toward a technology; findings indicated that individuals who had learned about robots in positive contexts, such as safety-critical applications, had higher levels of positivity toward the technology.

Understanding public perceptions is important because it is a critical early-stage step toward effective integration of technology into workplaces such that this integration occurs in an ethical and sustainable manner that does no harm to workers in the system. A good understanding of public perceptions surrounding an issue can help to support effective education, communication, and policy formation related to the issue (Morgan, 1997). However, a challenge exists in that it is difficult to assess attitudes toward something that respondents do not have direct experience with, for example, with systems that are in development or not easily accessible. During the early phases of design, it is common for user-centered design methods to inform product or system development. In the human factors and ergonomics (HFE) community, methods often include interviews with stakeholders to derive specifications and requirements (Maguire, 2001), usability evaluation of prototypes (Abras et al., 2004; Argyle et al., 2017), and observational methods such as contextual inquiry to identify how users interact with the technology (Beyer & Holtzblatt, 1999; Raven & Flanders, 1996). Nevertheless, user-centered design methods are often limited when it comes to assessing futuristic technology that may not be sufficiently developed to obtain robust user feedback. In response to this limitation, Mancini et al. (2010) proposed the ContraVision technique, a method for eliciting users' reactions through the presentation of opposing viewpoints in fictional narratives to potential end users.

Previous research has used the ContraVision technique, a method grounded in the human–computer interaction (HCI) domain, to identify potential user attitudes toward specific futuristic technologies, including those that do not yet exist or are not fully deployed (Mancini et al., 2010). The core of the technique centers around the creation of two opposing narratives: one, a "highly positive utopic" vision of the technology, and the other, a "highly negative dystopic" vision. Narratives are intended to engage the participant, and these can be told via film, illustration, audio recording, or written text (Mancini et al., 2010). In its first application, Mancini et al. (2010) used the ContraVision technique to explore users' reactions to wearable technology for assisting with health care and well-being. The authors concluded that presenting the same technology from two contrasting points of view elicited a wider spectrum of responses from the participants than by only presenting one viewpoint. The technique has been used in similar applications, for example, to explore users' understanding of and engagement with future smart grid technologies (Goulden et al., 2014), requirements for engineering adaptive software for IoT systems (Bennaceur et al., 2016), and societal acceptance of domestic energy Demand Response programs (Naghiyev et al., 2022).

From a methodological perspective, we argue that the ContraVision technique offers a useful approach for exploring future systems design in a way that has previously been underutilized in HFE research. The development of methods for designing and analyzing future systems from a human-centered viewpoint has often been within the purview of HFE, most notably from the systems ergonomics perspective (Wilson, 2014). In addition to user-centered design, methods employed in systems ergonomics offer a balance between qualitative and quantitative insights, integrated throughout the system design life cycle. ContraVision complements traditional HFE design and evaluation techniques, for example, cognitive walkthroughs (Mahatody et al., 2010), task analysis methods (Crandall et al., 2006), and Cognitive Work Analysis (Read et al., 2015; Salmon et al., 2016), among others. There has historically been close alignment between HFE and HCI methods, with approaches such as scenario-based design (Carroll, 1997), design fictions (Brown et al., 2016; Grand & Wiedmer, 2010), participatory design (Rogers et al., 2022), and ideation cards (Lockton et al., 2010; Wetzel et al., 2017) used successfully across both communities to ideate design solutions and explore human interaction with systems. Qualitative methods, like the ContraVision technique, provide a framework for encouraging individuals to think through a proposed concept or design systematically while considering a range of issues. Thus, the ContraVision technique has a key role in the HFE toolkit of methods for supporting the design and evaluation of future technologies.

The primary aim of this work was to generate insight into public perceptions and attitudes toward DMTs through the use of the ContraVision technique. Further to this, the secondary aim was to explore potential influences on perceptions of DMT portrayal in film-based provocations. Lastly, we consider the ContraVision technique in relation to existing HFE methods for exploring attitudes toward new systems. This work is novel as no previous research has applied the ContraVision technique to explore perceptions of futuristic digital technologies in manufacturing settings. The current work applies the technique to a new domain, focusing less on technology design itself and more toward identifying the major challenges and opportunities for DMTs as envisioned by potential future end users.

2 | METHOD

The ContraVision approach presents the same topic from two opposite points of view (Mancini et al., 2010). To this end, we prepared two scenarios: a utopic video presenting the future of digital technologies in manufacturing in an optimistic light and a dystopic video having a negative take on the future use of these technologies. While we do not expect either of the scenarios to represent the future accurately, they provide a way of eliciting a broader range of responses from the participants than would have been expected through a single scenario (Mancini et al., 2010).

The research questions explored in this study were:

RQ1: What are individuals' attitudes toward DMTs?

RQ2: How does the portrayal of technology in the ContraVision videos influence individuals' attitudes?

2.1 | Study design

The study adopted a mixed methods approach to address the research questions. The study used a between-subjects design to investigate the influence of DMT portrayal on public perceptions, without interference effects influencing responses to the utopic/dystopic scenarios. The portrayal was presented in two conditions: a utopic scenario and a dystopic scenario. Participants viewed either the utopic or dystopic scenario in the form of a video, each lasting about 3 min, followed by a questionnaire. Qualitative responses were examined via a thematic analysis (Braun & Clarke, 2006) to explore the reasoning behind attitudes toward the DMTs in question. The data were collected in November 2020 using an online survey distributed through the Prolific recruitment platform (https://prolific.co/).

2.2 | ContraVision video productions

Both fictional scenarios present a monologue by an imaginary manufacturing worker working for the local community factory in a small town. The full video recordings of the scenarios can be found in the University of Nottingham's research data repository (link: http://doi.org/10.17639/nott.7176). Content and production of the videos were developed in collaboration with an independent film production company. The development process involved the team of researchers identifying a set of DMTs of interest within the Industry 4.0 paradigm, which included industrial and collaborative robotics, distributed data technologies/IoT, human augmentation and physiological sensing systems, and data visualization technologies. These DMTs were then considered from opposing perspectives, such that the two films were intentionally designed to mirror each other in terms of topic and content. We purposefully took near-future scenarios for these perspectives, employing a design fiction paradigm, such that they would be possible within current society, as opposed to, for example, extreme dystopian views portrayed in science fiction. The research team and film production company worked together in an iterative process to draft the script based on these considerations in such a way that the spoken narrative in both videos discussed the identified themes in the same order from opposing viewpoints, per the ContraVision technique's approach (Mancini et al., 2010). Three iterations of the script were made and reviewed by the research team before a voice actor was hired to provide the narration for both films. The audio was then overlaid over a selection of relevant visuals gathered from an industry reusable footage database to emphasize the points being made (although note: these visuals alone would not necessarily depict utopian or dystopian views without the narrative). The videos themselves also went through one iteration of feedback from the research team to make sure that the narrative communicated the key points clearly.

2.3 | Content of ContraVision narratives

Both scenarios begin by explaining that the factory has just undergone a period of significant change involving the integration of new digital technologies into routine work. The worker from the utopic scenario has a positive opinion about the changes, whereas in the dystopic scenario, the worker communicates his negativity and hesitation about speaking about this topic and making his opinions public. Overall, the main difference between the scenarios is the way in which the factory management has implemented the DMTs; in the utopic scenario (Figure 1), a user-centered, inclusive, and ethical design approach leads to direct benefits to workers, whereas in the dystopic scenario (Figure 2), DMTs have been introduced to oversee and control the work environment, leading to distrust, anger, and reduced productivity among workers.

Within the scenarios, the worker's monologue focuses on his perspectives on the introduction of several different DMTs, including wearable sensors for operator state monitoring, distributed data

FIGURE 1 Still imagery from the fictional scenario depicted in the utopic video

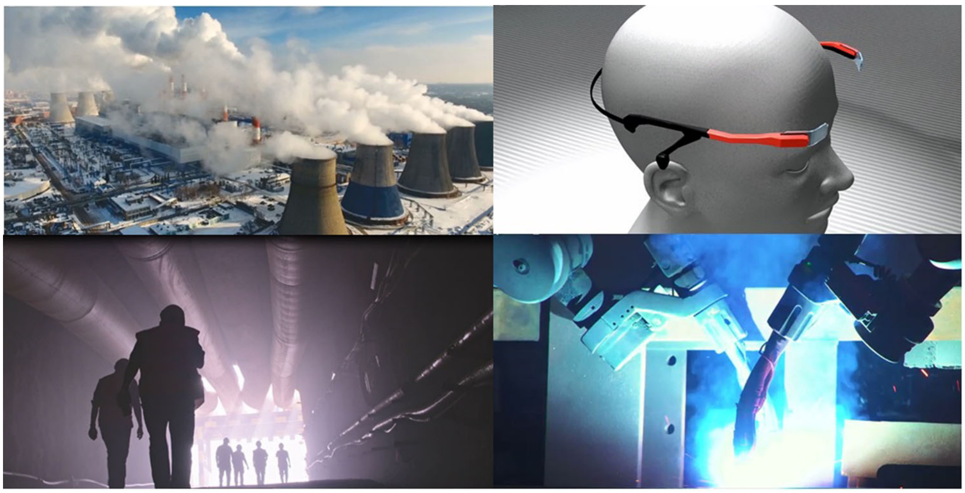


FIGURE 2 Still imagery from the fictional scenario depicted in the dystopic video

technologies, and industrial robotics. In the utopic scenario, the worker discusses having his heart rate and brain activity monitored for the sole purpose of improving wellness in the workplace while encouraging colleagues to help each other stick to wellness programs. In one excerpt, the protagonist states that the technologies are used to enable wellness, and that "we can even buddy up with a colleague to help each other stick to our individual wellness program. Paul Dixon and I are currently leading in our department." However, in the dystopic scenario, the same technologies are shown, but this time, they are not being used for the same purposes. The worker explains the same technologies are not being used out of an interest in the workers' wellness, but instead to track their levels of concentration, physical activity, and other metrics that are converted into a performance score. This is emphasized when the worker states, "We all get a score that takes into account all types of metrics. This score is also affected by how much we speak to each other about non task related things… We've noticed that no one is able to speak with [Paul Dixon] for more than a few seconds before the system moves him on."

The advantages of distributed data and systems, coupled with virtual reality capabilities, are described in the next scene of the utopic scenario, where the worker proudly speaks of his hydroponic garden project that is being developed in collaboration with experts from around the world. Real-time translation capabilities as well as seamless integration of their models and data allow for distributed teams to easily collaborate. However, in the dystopic scenario, the same distributed data technologies are not put to such uses and instead are used by the factory in a way that lacks transparency. The worker expresses suspiciousness toward the promise that individuals will not be able to be identified from their data and that the data will not be shared, especially when workers learn that the company records their behavior outside of work.

In addition, the worker in both scenarios describes the integration of industrial and collaborative robots into their workplace. In the utopic scenario, the worker describes forming a connection with the robot he uses at work, even assigning it a name, saying, "When I'm working with my robot, I call him Bob, he is able to sense when I am losing concentration, but also when we are working well, he is able to anticipate my movements and we work as one together." Their interactions appear to be natural and beneficial for everyone involved. In the dystopic scenario, the situation is the opposite; the robot has not been adapted to interact effectively with the workers, and it turns out that the issues in human–system integration are negatively affecting the productivity score of our protagonist. This is described by the protagonist, saying, "We have a new process the robot and I are having trouble collaborating on. I think it learned with someone much smaller than me. Basically, it's trying to weld before I put a certain component in, which makes it really awkward to reach. It ends up taking more time and it's killing my [productivity] score."

The final discussion point in the scenarios focuses on sensor data, relating closely to the physiological/wearable sensors and distributed data technologies discussed previously. In the utopic scenario, sensor data are used by the company to assess the capabilities of workers, with the worker providing an example where a task was redesigned after data showed the original task created significant worker fatigue. In the dystopic scenario, the same data are used to compare workers in facilities around the world, where all compete against each others' productivity scores and no recognition is given for positive behaviors.

2.4 | Procedure

The online form introduced the research goals to the participants, and if they agreed to take part, they were redirected to a Microsoft Forms survey containing the informed consent form. Then, participants were asked to watch one of the video conditions and to complete a questionnaire consisting of both quantitative and qualitative questions. The questionnaire, shown in Table 1, was designed following a review of public perceptions questionnaires in other domains (Castell et al., 2014) and a discussion within the research team, which identified key areas of interest; from this process, questions were designed to collect information on individual attitudes toward the intersection of digital technology and manufacturing. These were piloted within the project team to ensure meaning was clear and addressed the concepts of relevance.

After the questionnaire was completed, participants optionally provided data on age, gender, level of education, and experience in manufacturing. Following this, they were redirected to the Prolific page for payment.

2.5 | Data processing and analysis

Out of the initial participants, 32 were removed based on the time they took to complete the survey. Participants who took less than 3 min plus the duration of the video to complete the questionnaire were determined not to have given the questions sufficient consideration, so these data points were removed; indeed, some participants actually took less than the duration of the video, indicating that they most likely did not watch most of it. After this removal, additional recruitment occurred to create equal-sized groups between conditions. In total, data from 134 participants were retained from a total of 166 submissions.

The data analysis consisted of an initial analysis of the quantitative data followed by an analysis of the qualitative responses. For the quantitative data, a Mann–Whitney *U*-test was used to determine if there were any differences for questions 1 to 14, between the utopic and dystopic conditions. In the case of the qualitative data, a thematic analysis was conducted in accordance with the approach set out by Braun and Clarke (2006). Guided by the thematic analysis, data were coded, the codes were examined, and where similarities were found sorted into themes and accompanying subthemes.

2.6 | Participant data

The analysis included data from 134 participants (61% females, 39% males), all older than 18 years (10%, 18–21; 26%, 21–29; 26%, 30–39; 18%, 40–49; 10%, 50–59, 8% 61+). An equal number of participants took part in both conditions, and the proportion in each age group was comparable between conditions. In terms of educational attainment level, the majority of participants had completed a degree in higher education (undergraduate or postgraduate level), while a subset of the sample held GCSEs, A-Levels, or equivalents. Figure 3 presents the breakdown of educational attainment within both conditions.

Participants also represented a range of familiarity with manufacturing. When probed about their experience level in this field, where 1 represented "Never worked in manufacturing" and 5 "Highly experienced in manufacturing", a small proportion had some degree of experience (31.3%), whereas the majority had none (68.7%).

Participants were recruited using the Prolific platform and custom pre-screening was applied to select only participants from the United Kingdom. Participants were provided with £1.88 for an estimated 15 min of their time (the equivalent of £7.52/h); in most cases, it took less than 15 min to complete the study, and therefore the average pay was equivalent to £15.41/h. This study was approved by the University of Nottingham's Faculty of Engineering Ethics Committee.

3 | RESULTS AND ANALYSIS

3.1 | Attitudes toward DMT

The first research question sought to explore individual perceptions and attitudes toward DMTs, independent of Utopian/Dystopian conditions. Within the questionnaire, Questions 7–14 were designed to capture broad attitudes toward manufacturing and DMTs, and responses were given on a scale of 0 (Most negative/Strongest disagreement) to 6 (Most positive/Strongest agreement). In terms of general perceptions, regardless of the video condition to which they were assigned, participants' perceptions toward DMTs were widely distributed but were overall slightly positive (median [Mdn] = 4,

TABLE 1 Questionnaire

No.	Question	Scale
The first 6 questions refer to the videos that were watched by the participant		
1	How positive would you feel about working for this company?	0 (Very negative)–6 (Very positive)
2	Would you trust this company with your data?	0 (Not at all)–6 (Fully trust)
3	If you worked in a manufacturing company, do you think such technologies would make your job easier?	0 (Not at all)–6 (Very likely)
4	If you worked for such a manufacturing company, would you be happy to wear sensors collecting physiological data?	0 (Not at all)–6 (Very happy)
5	If you worked for such a manufacturing company, would you be happy to work alongside a robot?	0 (Not at all)–6 (Very happy)
6	If you worked for such a manufacturing company, would you see the benefits of distributed data technologies?	0 (Not at all)–6 (Yes)
The following questions refer to digital manufacturing technologies in general		
7	Overall, how positive or negative do you feel about digital manufacturing technologies?	0 (Very negative)–6 (Very positive)
8	Overall, how positive or negative is the impact that manufacturing has on:	
	1. The UK as a whole	0 (Very negative)–6 (Very positive)
	2. Your local community	0 (Very negative)–6 (Very positive)
	3. Your family	0 (Very negative)–6 (Very positive)
	4. Your individually	0 (Very negative)–6 (Very positive)
9	Overall, how positive or negative is the impact that digital technology has on:	
	1. The UK as a whole	0 (Very negative)–6 (Very positive)
	2. Your local community	0 (Very negative)–6 (Very positive)
	3. Your family	0 (Very negative)–6 (Very positive)
	4. Your individually	0 (Very negative)–6 (Very positive)
10	Digital technology has an important role to play in meeting the challenges the UK faces	1 (Strongly disagree), 2 (Tend to agree), 3 (Neutral), 4 (Tend to agree), and 5 (Strongly agree)
11	Digital technology provides opportunities to improve the productivity of manufacturing systems	1 (Strongly disagree), 2 (Tend to agree), 3 (Neutral), 4 (Tend to agree), and 5 (Strongly agree)
12	Digital technology can lead to improved efficiency for people working in manufacturing	1 (Strongly disagree), 2 (Tend to agree), 3 (Neutral), 4 (Tend to agree), and 5 (Strongly agree)
13	Digital technology can help to improve opportunities for individuals to manage their wellness	1 (Strongly disagree), 2 (Tend to agree), 3 (Neutral), 4 (Tend to agree), and 5 (Strongly agree)
14	Large manufacturing companies may be able to benefit from digital technology, but smaller companies may not get as much benefit	1 (Strongly disagree), 2 (Tend to agree), 3 (Neutral), 4 (Tend to agree), and 5 (Strongly agree)
15	Which of the following topics, if any, would you be most interested in learning more about with regard to manufacturing? Please use the arrows on the right-hand side to rank the subjects	1 (Ethics), 2 (Physiological data), 3 (Distributed data), and 4 (Robotics)
16	Do you have any other thoughts about the above subjects?	Open-ended response
17	Is there anything further you would like to share about digital manufacturing technologies?	Open-ended response

interquartile range [IQR] = 2–5). Participants slightly agreed that digital technology could help to meet challenges faced across the United Kingdom (Mdn = 4, IQR = 4–4.25) and that they could also offer new opportunities to help individuals manage their own wellness (Mdn = 3.5, IQR = 3–4). When asked to reflect on the impact that digital technologies have had on a range of entities, participants were largely positive toward their impact on a country- and community-wide scale, as well as to the level of the

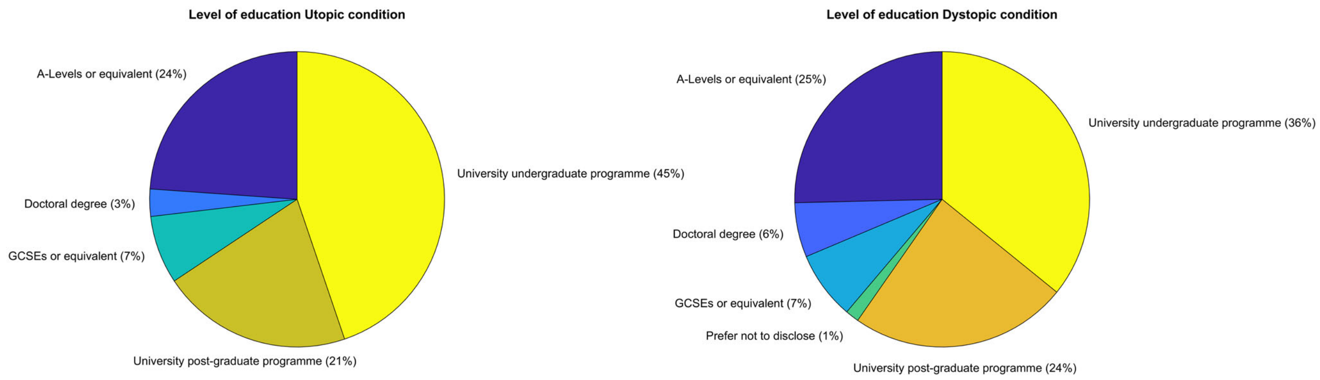


FIGURE 3 Level of educational attainment within both conditions

FIGURE 4 Ratings of perceived impact of digital technology on entities of different scales

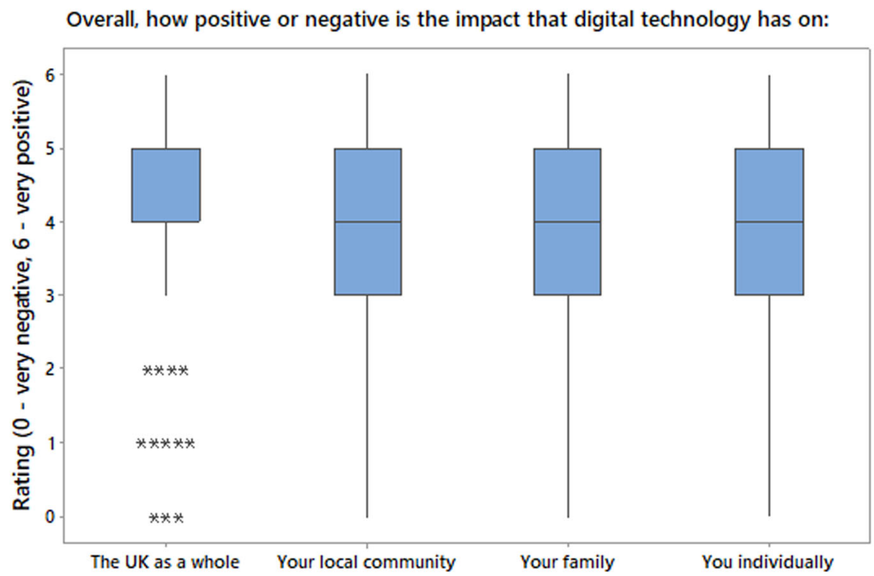
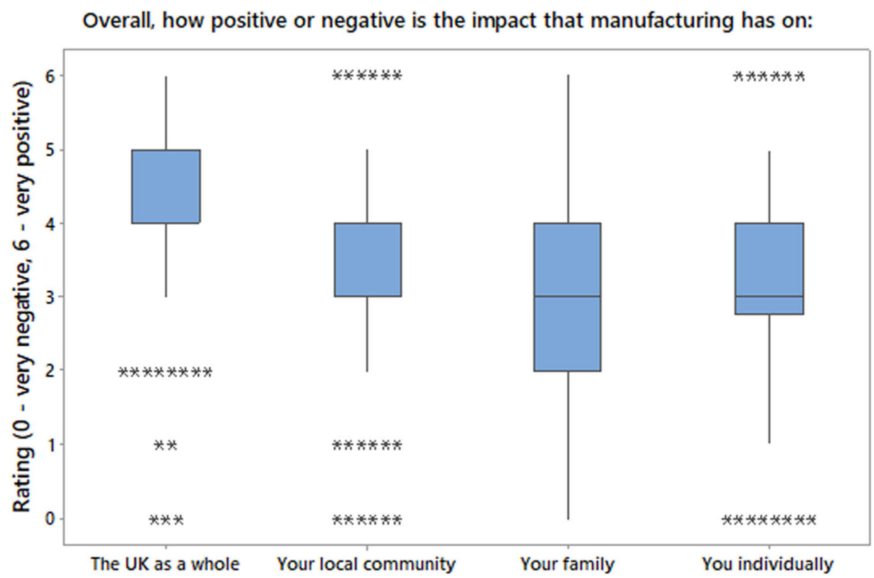


FIGURE 5 Ratings of perceived impact of manufacturing on entities of different scales



participant themselves and their families; results are shown in Figure 4.

In contrast to the positive perceptions of digital technologies, perceptions of the manufacturing industry were generally more neutral (Figure 5). Although participants largely felt that manufacturing had a positive impact on the United Kingdom as a whole (Mdn = 4, IQR = 4–5), responses were more neutral toward its impact on communities (Mdn = 4, IQR = 3–4), the participants' families (Mdn = 3, IQR = 2–4), and the participant themselves (Mdn = 3, IQR = 2.75–4). With respect to solving manufacturing challenges, participants also slightly agreed the DMTs could support improvements to productivity (Mdn = 4, IQR = 4–5) and human resource efficiency (Mdn = 4, IQR = 4–5). Interestingly, when asked about the direct benefits of DMTs to companies of varying sizes, responses revealed a perception that large companies may benefit more than small-to-medium enterprises (Mdn = 4, IQR = 3–4); this indicates a lack of understanding regarding the range of benefits that can be gained from DMTs.

3.2 | Thematic analysis: Perceptions and concerns surrounding DMTs

To explore perceptions surrounding DMTs more deeply, a thematic analysis of the open-ended responses was performed to identify a set of key themes associated with positive and negative perceptions of the technologies. For the analysis, the qualitative data were gathered from open-ended questions at the end of the questionnaire (Questions 16 and 17). Out of the full sample of participants (*N* = 134), only 66 answered or responded to the open-ended questions. Of these, four were removed due to the aforementioned minimal time spent answering the questions. The remaining respondents (*N* = 62) were thus judged to have responded adequately to the question and within an appropriate amount of time, and as such, these responses formed the basis for the thematic analysis. The data were analyzed per condition for utopic and dystopic perspectives. Responses illustrated the ContraVision technique's utility for eliciting a range of opinions. Challenges and concerns were identified relating to the themes of personal data management, respect toward people, viewpoints on the future, impacts on wider society, and impacts to work environments as a result of technology introduction; these themes are discussed in the following subsections.

3.2.1 | Personal data

The theme of “personal data” emerged during the analysis, representing attitudes that participants held toward the individual employee's personal data, which is to be collected by the systems in the utopic vision. Subthemes were identified as relating to attitudes toward data “capture” and “data usage.”

Participant feedback indicated an interest in the topic of data capture. One quote exemplified concern about this topic, particularly regarding the employee monitoring in the workplace, stating, “What kind of dystopian ideal is this? Forcing workers to be biometrically monitored during their time at work?” (Participant 16U). This quote relates to the scenario presented in the video in which data on employees were captured throughout the day, whether they were at work or not. As presented in the videos, monitoring in real-world environments ranged from evaluating productivity to physiological health-related assessment for individuals, the latter referred to in the quote. This subtheme reveals concerns with the notion that capturing physiological data about employees is “a dystopian ideal” or that certain forms of it are less palatable than others; for example, one participant stated that they were, “OK with heart and breathing rate being recorded, [but I] find brain activity a bit creepy” (Participant 54U).

Participant responses also indicated concerns related to how personal data is used and shared, captured in the “data usage” subtheme. One participant stated, “If the data is shared with an employer, [I] think [it's] too much data shared with others” (Participant 51U). Participants voiced concerns with companies using any sort of data of a personal nature, questioning how personal data (e.g., productivity measures based on physiological data) would be passed between parties or kept solely by the individual they represent. In line with this, one participant also expressed uncertainty about how data would be analyzed, asking: “How are our own personal (out of work) factors taken into consideration in a way that does not prejudice the analysis[?]” (Participant 13U) Taken together, these comments point to concerns about data misuse and a lack of clarity surrounding analytical frameworks. As the second quote indicates, providing detail on the context in which data are analyzed may provide greater confidence in supporting decision-making. Second, there is an assumption that this personal data will be analyzed on an individual basis. It may be possible that respondents' attitudes would differ if data were aggregated over a large data set.

3.2.2 | Impacts to people

The next theme identified was “impacts to people,” concerning individuals as a collective rather than specific individuals or the wider society. This can be evidenced by the subthemes of possible discrimination and the perceived degradation of human contributions in manufacturing workplaces.

Within this theme, the first subtheme focused on concerns related to “potential discrimination” against workers. Participants picked up on the idea that the certain workers may not be able to acquire work if their performance is being assessed. There are overlaps here with the concerns expressed in the “personal data”' theme, in that the concept of data runs throughout, but differs in that the discrimination aspect looks at the broader implications of data use.

One participant noted that, “I think if [you] measure people's heart rate etc. in jobs, some people will never be able to get a job” (Participant 41U). This sentiment suggests that the participant noted how some members of society may struggle to find meaningful employment if they do not match the model of an ideal employee in terms of the physiological monitoring characteristics.

The second subtheme was associated with concerns about changes to how humans could be perceived as an actor within manufacturing systems; this is described by the title, “degrading of human value.” Participants noted a disconnect between how worker contributions are perceived currently and how they could be perceived with increased use of these digital technologies. One participant commented, “it could be quite intrusive, and means that the person is almost like a robot" (Participant 1U). This example presents the degrading of the human values by comparison against a machine, which is synonymous with constantly repeated actions and showing little emotion. This is echoed in another participant's quote, which stated that, "It scares me that we are becoming a society that will depend mainly on data. I fear that it will remove any connection to reality" (Participant 49U). The data referred to could also be linked to the degradation of human values, in the sense that rather than making personal decisions, we start making all decisions based on data.

3.2.3 | Future

The final theme that emerged from participants in the utopic condition was that of the "future," encapsulating perceptions related to the progression of technological trends over time. Within this theme, subthemes related to expectations surrounding the march of progress and describing general attitudes held by participants toward this.

The first subtheme identified was around the nature of the perceived trend toward increased use of technology, both in and out of work-related contexts. Participant comments often reflected a belief that technological progress is ever moving forwards, with one participant stating that, "[digital manufacturing] clearly is, and has been for sometime, the future direction of manufacturing" (Participant 48U). The perception of the direction of travel within the industry is unambiguous in the comments, and one of the key aspects became apparent, that participant responses suggested they felt as if there were no alternatives to this persistent march of technological advancement, with some participant responses suggesting discomfort with this trend.

Two additional subthemes emerged relating to a "positive outlook" versus a "negative outlook" on future technology. These subthemes may seem mutually exclusive, but there is an argument that some participants held mixed feelings toward the technologies. With regard to the "positive outlook" subtheme, one participant commented on the potential for DMTs to affect individuals by stating it was "amazing how it can improve productivity" (Participant 42U). While it is difficult to ascertain from the participant's comment whether the technology's perceived benefits to productivity are within or outside of work contexts, other responses suggest a general positive attitude toward the potential benefits that digital technologies can bring to individuals.

In contrast, the "negative outlook" subtheme related to how technology is perceived in a negative way as it moves into the future. One participant questioned the consequences of moving toward technological advancement shown in the video, saying, "[…] i wonder how much robots impact people's jobs, especially when so many more people have been made redundant" (Participant 31U). One idea from this to consider further is the use of the term "wonder," which presents a slight uncertainty of the future, with the comment around job losses adding a negative context to this uncertainty. Further, a negative comment can be found within the next quote: "I think this technology will be used to exploit workers rather than improve their workplace. Why would technology make the workplace better if the people in charge have the same ethics codes and interests (i.e., profit) as before?" (Participant 47U). It is difficult to be sure what element of the technology will be used to what end, but there is this perceived sense that the technology will generally be used in a negative way.

3.2.4 | Impacts on wider society

One theme that emerged from participant responses in the dystopic condition was attitudes and concerns around the "impact on wider society." Participant responses in this theme related to attitudes toward the broader lens of society, rather than on perceived impacts at the individual level.

The first subtheme revolved around a "perceived positive impact for industry." Compared to participants in the utopic condition, dystopic condition participants assumed a perspective that was more industry-focused when discussing the effects of the future DMTs. Interestingly, responses to the dystopic video indicated a higher level of positivity toward technology than utopic responses; in one example, a participant commented, "This sort of technology is certainly exciting and offers benefits to productivity and wealth creation[…]" (Participant 75D). Further illustrating this point is another participant's comment, stating that they "… believe digital technology brings improvement for businesses" (Participant 56D). In combination, these quotes suggest that some individuals perceive there to be DMT benefits and thus they have a positive view of the technology.

The second subtheme associated with impacts on wider society related to how DMTs could affect how society views the value of the individual worker, captured with the title "degradation of human value." Thoughts in this subtheme transcended differences between utopic and dystopic perspectives, overlapping with the subtheme of the same name that emerged from the utopic perspective feedback. The analysis identified some negative perceptions of DMTs, especially the physiological monitoring systems, with one participant commenting that they thought that "physiological data collection turns the human into an [inefficient] machine" (Participant 76D). This conceptualization of humans becoming machine-like emerged from responses from multiple participants, indicating that concerns about the blurring of boundaries between the value that humans offer to work systems versus what technology can offer must be addressed. This is also illustrated through another participant's comment, who stated that "… humans should not be treated as robots, and should fill roles that cannot be done as well as by robots" (Participant 74D). Comments captured within this subtheme indicate prevalent concerns relating to fears that workers will be expected to perform to the same level as automation, instead of systems leveraging the unique skills of humans and technology to optimal effect

3.2.5 | Impacts on work environments

Participant responses also indicated concerns with potential "impacts to work environments"; this forms the second theme identified from responses within the dystopic perspective. Compared to the first theme, which focused on societal implications of the technology, responses captured in this theme focused on perceptions of impacts on a smaller scale, such as localized effects found within a business.

Within this theme, a subtheme was identified surrounding perceptions surrounding the impact DMTs could have on human interactions while at work, entitled “less interpersonal interaction.” To illustrate this subtheme, in relation to the workplace shown in the video, one participant commented, “It is a very controlling environment which encourages isolation between workers thus not encouraging interaction and therefore not benefiting by group learning” (Participant 61D). Further pointing toward potential isolation caused by introducing more technology, another participant was concerned that “… it eliminates human interaction and places robots in place of the workers” (Participant 65D). Comparing the two quotes, a common strand is a concern that increased technology will reshape the social dynamics of future workplaces, putting greater value on contributions of technology, and reducing sources of wellness for human workers like interpersonal interaction.

Lastly, concerns surrounding “job security risks” emerged from dystopic participant responses, with comments relating to the participant's attitudes toward the impact of DMTs on job security. One participant voiced concern over ethical implementation and employee safeguarding, stating, “[…]but it is also important to introduce them in the right way to avoid mass redundancies without other jobs being available or a universal basic income like alternative” (Participant 21D). Concern for job security is further evidenced in another quote where the participant felt it was important to “[learn] how robots and humans can work together so that humans don't [lose] their jobs to robots” (Participant 60D). This comment further reinforces the idea job security is a potential issue for DMT.

TABLE 2 Mann–Whitney *U*-test results

No.	Median utopic	Median dystopic	Mann–Whitney *U*-test	Asymptotic significance (two-tailed test)
1	4	0	402	**$p < .0005$**
2	3	0	619	**$p < .0005$**
3	5	2	726.5	**$p < .0005$**
4	3	0	885.5	**$p < .0005$**
5	5	3	1042.5	**$p < .0005$**
6	5	3	910.5	**$p < .0005$**
7	4	3	1139.5	**$p < .0005$**
8.1	5	4	1468.5	**$p < .0005$**
8.2	4	3	1603	**$p = .003$**
8.3	3	3	1833	$p = .055$
8.4	3	3	1679	**$p = .009$**
9.1	5	5	1893	$p = .103$
9.2	4	4	1978.5	$p = .222$
9.3	4	4	2249	$p = .984$
9.4	4	4	2050	$p = .375$
10	4	4	1715	**$p = .007$**
11	4	4	1739.5	$p = .013$
12	4	4	1549	**$p = .001$**
13	4	3	1514	**$p = .001$**
14	4	4	2453	$p = .325$

Note: Significant results indicate more positive attitudes toward DMTs in the utopic scenario. Question numbers refer to those shown in Table 1. Significance at the $\alpha = .05$ level indicated in bold font.

3.3 | Attitudes toward technology versus ContraVision portrayal

In our second research question, we sought to identify the effects of how the DMTs portrayed in the videos influenced attitudes toward them. To this end, a series of Mann–Whitney *U*-tests analyzed each of the Likert scale questionnaire items to determine if there were differences in ratings between the utopic and dystopic conditions; results are shown in Table 2. In addition, for each one of the questions, the distributions of ratings for both conditions were assessed by visual inspection. As shown in Table 2, participants who viewed the utopic scenario reported significantly more positive attitudes to many of the questions as compared to viewers of the dystopic scenario.

The first six questions in the survey referred directly to participant perceptions of the video content, and responses were rated on a seven-point Likert scale (0 = Most negative, 6 = Most positive). As shown in the Mann–Whitney *U*-test analysis, a significant difference was observed between the mean ranks of responses for each question. A closer examination of the data shows that participants in the dystopic condition were significantly more negative toward the company depicted in the video (Mdn = 0, IQR = 0–1) compared to the utopic video participants (Mdn = 4, IQR = 3–5). Participants in both conditions reported low levels of trust in the company to manage their personal data (Mdn = 0, IQR = 0–1), although utopic participants veered slightly more to the neutral/positive end of the spectrum (Mdn = 3, IQR = 2–4). When asked whether they thought the DMTs represented in the videos would make a job in manufacturing easier, utopic participants largely agreed that it would (Mdn = 5, IQR = 4–6), while dystopic participants responded more negatively (Mdn = 2, IQR = 1–3). dystopic participants reported mixed opinions on their level of acceptance of working with robotics (Mdn = 3, IQR = 2–4) and distributed data technologies (Mdn = 3, IQR = 1–4), but were highly negative toward operator monitoring systems based on physiological sensing (Mdn = 0, IQR = 0–1). Interestingly, while utopic participants were highly positive toward robotics (Mdn = 5, IQR = 4–5) and distributed data technologies (Mdn = 5, IQR = 4–5), their responses to physiological sensing systems were more tempered, with a wide distribution spanning negative to positive responses (Mdn = 3, IQR = 1–4).

4 | DISCUSSION

To examine public attitudes to DMTs and how the portrayal of technology via the ContraVision technique influences these attitudes, we explored these topics using a video-based approach. Two contrasting videos portrayed DMTs, addressing human–robot collaboration, physiological data collection, distributed data, and ethics. The utopic scenario positioned these technologies in a positive light, while the dystopic one explored the negative outcomes that might come from deploying such technologies. Participants were exposed to either the utopic or the dystopic condition and were then asked to complete the questionnaire.

4.1 | RQ1: Attitudes toward digital technology and manufacturing

Overall, findings suggest that participants held moderately positive attitudes toward DMTs, with utopic viewers responding slightly more positively and dystopic viewers more neutrally. However, regardless of condition, the median value of responses indicated that participants tended to agree that digital technology could provide new opportunities to improve productivity in manufacturing settings. Although viewers in both video conditions tended to agree that digital technology could lead to improved efficiency in manufacturing, it is interesting to note the significant difference in the distributions of responses; responses from viewers of the utopic video were much more positive toward potential efficiency gains from DMTs than responses from viewers of the dystopic video. Digital technologies were also perceived in a positive light when considered for supporting individual wellness, although participants in the dystopic condition responded more neutrally to this aspect. Finally, when asked about the perceived impacts that digital technology could have on companies of different scales, participants in both conditions tended to agree that larger corporations may benefit more than smaller companies. This may indicate the need for future communications on the impact of DMTs for end users of all scales to improve the accessibility and perceived usefulness of such tools.

The current findings complement previous work in HFE studies related to attitudes toward technology adoption and Industry 4.0. Across both the qualitative and quantitative metrics, the current work indicated mixed perceptions of DMTs and future manufacturing systems. For future digital technologies such as those explored here, perception and attitudes toward technology can play a significant role in an individual's willingness to adopt it (Bitkina et al., 2020). Design and organizational factors influence attitudes toward future systems; for example, factors including cost, usability, trustworthiness, flexibility, cost, and learnability have been identified as critical challenges in the design of virtual human factors tools such as digital human models and virtual reality (Perez & Neumann, 2015).

Within the field of HFE, frameworks such as the Technology Acceptance Model (TAM; Davis et al., 1989) and the Automation Acceptance Model (AAM; Ghazizadeh et al., 2012) are well-established in the literature for predicting the successful adoption of a new product or system. The original TAM predicts acceptance via actual system use, which is moderated by an individual's intention to use the technology, which in turn is influenced by attitudes toward the system, perceived usefulness, and perceived ease of use. In an extension of the original model, the AAM incorporates the moderating effects of compatibility, trust, and external variables on the TAM constructs (Ghazizadeh et al., 2012). As we have demonstrated, ContraVision can be used to delve into factors influencing technology acceptance before actual system use is possible. Although we did not structure the current study to explore acceptance specifically, our findings provide insight into TAM-related constructs such as perceived usefulness and attitudes toward using the technology. In the context of DMT use, our findings point to challenges that can be addressed in the early stages of human-centered systems design to streamline the development of future digital manufacturing workplaces.

Through the questionnaire and thematic analysis, several challenges and concerns were identified relating to the DMTs presented in the videos. Concerns primarily focused on the use of personal data and its impacts on individuals, society, and the future of work. Specifically, participant responses centered around concerns related to: ensuring ethical, fair, and transparent capture and use of personal data; minimizing negative impacts of technology on job security; minimizing negative impacts of technology on individual wellness; optimizing the relationship between business benefits and individual benefits from DMTs; widening participation in DMT implementation to enterprises of all scales; educating and informing the public on both digital technology benefits and manufacturing industry benefits across local and national communities.

4.1.1 | Ensuring ethical, fair, and transparent capture and use of personal data

Among the expressed viewpoints, ethical and transparent collection and use of personal data were viewed as a matter of serious concern. Previous work on the acceptance of DMTs, such as with distributed data technology, has found that while such systems can benefit organizations and individual users, technical and social challenges must be addressed, particularly with regard to ensuring trustworthiness, privacy, and data security (Atzori et al., 2010; Fast & Horvitz, 2017; Zubiaga et al., 2018). In the current work, participants voiced fears that personal data could be used by employers to discriminate against workers, creating work environments more focused on evaluating workers based on sensing and remote observation (e.g., via the physiological sensing-based operator state monitoring system shown in the videos) rather than on demonstrable behaviors and performance. Furthermore, some technologies were seen as potentially invasive, posing risks to individual privacy and security. In a survey of European service organizations on IoT security, Asplund and Nadjm-Tehrani (2016) observed that service availability was prioritized more highly than data confidentiality. As DMTs continue to mature and be integrated into workplaces, organizations and regulatory bodies must address the potential pitfalls and misuse of personal data; ongoing work in this area includes the development of "right-to-know legislation" requiring systems to show the user what data is collected about them and providing the option for an individual to remove their data (Weber, 2010).

Although the present research shows that members of the UK public hold concerns about DMT data capture and its impact on individual lives, longitudinal research indicates that perceptions toward technology evolve as systems mature. Zubiaga et al. (2018) conducted a longitudinal analysis of social media posts related to IoT technology, finding that public perceptions toward trust, security, and privacy grew more positive over the analyzed timeframe. The authors identified specific concerns related to IoT technology and related concepts, including analytics, machine learning, big data, security implications, and machine-to-machine communication. Over the time period, posts increased in positivity toward analytics and machine learning topics but became significantly more negative toward security topics. Similarly, in a longitudinal analysis of public reports on AI, Fast and Horvitz (2017) found that ethical concerns related to AI were appearing with increasing frequency in public dialogs. These findings align with the present study's findings, where some participants reported generally positive views toward DMTs and digital technology in general but also expressed concern for ethical, secure, and fair use of data, particular types that are personal in nature.

4.1.2 | Maximizing business benefits while minimizing negative impacts on job security and wellness

Throughout history, new technology has frequently led to cultural anxiety surrounding its introduction into the workplace; concerns have namely related to machines replacing human workers and a resulting degraded quality of life for workers (Mokyr et al., 2015), concerns that were reflected in the current study. Records dating from the 18th century through to the modern era show that economists and policymakers have long debated the potential implications of new workplace technology on society, but that many predicted impacts have not been fully realized (Autor, 2015; Mokyr et al., 2015). While the emergence of advanced digital technologies such as AI and sensing have generated familiar predictions, scholars suggest that the functions performed by such systems may change the nature of work, but that humans will still play a significant and meaningful role in such work systems (Mokyr et al., 2015). Similarly, challenges associated with job security and individual wellness became apparent from participant responses. Distinct from concerns about ethics, privacy, and security, responses indicated that participants held concerns that DMTs could reduce or remove the need for human workers. In the case of operator state monitoring technologies, participants were also concerned that these could be used to discriminate or micromanage workers if not managed responsibly. This is of significant interest given the recent rise in interest in sensing technology for improving operational safety by tracking parameters such as mental workload (Argyle et al., 2021; Marinescu et al., 2018), situation awareness (Argyle et al., 2020; Zhang et al., 2020), and fatigue (Sikander and Anwar, 2018); based on participant responses, we argue that research should focus not only on developing functional technologies but that design and implementation should assume a user-centered design paradigm, focusing on creating systems that result in safer operations and an engaged, satisfied workforce. These concerns link closely with a challenge for the industry to ensure that DMTs have positive impacts on worker wellness, holistically considering both physical health and mental well-being. In line with this, previous work has observed increasing levels of fear surrounding the loss of control over technologies used to inform critical decisions and decreasing levels of positivity toward the impact of AI on human work (Fast & Horvitz, 2017). In relation to distributed data technologies, organizations have responsibilities toward their employees to maintain data security; with regard to the gathering and analysis of personal data, allowing users to have a degree of control over these processes can enhance trust in such systems (Maple, 2017).

In light of these concerns, we suggest that DMT integration programs consider not only how to facilitate the active participation of users but also how to communicate the potential values of the technology in personalized ways to fit the target audience. For example, previous research has shown that workers with different backgrounds will consider different factors when whether or how to use workplace technology (Morris et al., 2005). In an investigation based on the Theory of Planned Behavior (Ajzen, 1985), Morris et al. (2005) found that workplace technology adoption perceptions varied, identifying significant gender differences as participant age increased, but not among younger participants. Furthermore, among the participants in the older age group, the authors found that men's perceptions toward adopting a particular technology were most influenced by their attitudes toward it, incorporating perceived usefulness and positive/negative perception of using the tool. In contrast, women in the older age group held attitudes that were most influenced by perceptions surrounding social norms, ease of using the technology, as well as an attitude toward the technology. Although we were not able to explore gender or age differences in the current study, these findings provide insight into addressing societal challenges around ensuring that DMTs are designed and implemented in a user-centered manner, accounting for differences in worker characteristics that may affect intentions to use the systems.

It is important to note that, despite long-held cultural anxiety around new technology, digital technologies have the potential to enhance work flexibility and quality of life, two aspects that were limited during previous industrial revolutions (Mokyr et al., 2015). Recent research on the Millennial workforce has suggested that individuals value work that offers flexible work patterns, challenging tasks, roles of responsibility, and opportunities for professional development (Schaar et al., 2019). We hypothesize that communicating how DMTs could enable increased flexibility and stimulating challenges may help to shift perceptions around DMTs within younger generations of workers, although additional research is needed to explore this further.

4.1.3 | Widening participation to enhance social and organizational readiness

The final set of concerns identified through the study pointed toward parallel challenges involving reducing barriers to entry into Industry 4.0 and expanding societal awareness and knowledge of potential uses of digital technology in manufacturing. Widening participation in Industry 4.0 has the potential for great productivity improvements in manufacturing, with benefits for enterprises of all scales, but it has also been shown that Industry 4.0 readiness is a function of enterprise size (Stentoft et al., 2019).

To optimize the benefits of DMTs to enterprises of all scales, barriers to adopting Industry 4.0 technology must be identified and addressed. In part, overcoming barriers associated with stakeholder acceptance and lack of worker experience with DMTs requires improved education for the public. In the current study, responses indicated that the portrayal of DMTs influenced participant perceptions of the DMTs; this aligns with previous research on public perceptions of robotics. In a survey of the UK public, the majority of respondents supported using robotics in safety-critical applications such as manufacturing and space exploration, but fewer supported robotic technology in more social applications such as caring roles (Castell et al., 2014). In terms of communication, the survey findings indicated that informational campaigns may benefit from focusing on specific applications of technology rather than a general domain; within the group of respondents that opposed technology in general domains, there was a higher level of support for robotic technology to perform specific tasks. The authors posited that this may have been due to difficulties with imagining robotic applications with which individuals have little experience but that providing specific examples can provide clarity. This hypothesis is supported by the findings from the current study, which demonstrates the methodological contribution of the ContraVision technique for providing engaging, specific contexts to support scenario-based design processes for technologies.

Lastly, the current study's findings indicate that while respondents may have viewed the manufacturing industry as having a great impact on the national scale, there was slightly less local or personal relevance. It is possible that the lack of personal experience with manufacturing and/or DMTs influenced perceptions (Castell et al., 2014), and further research is needed to explore the impact of educational and public awareness campaigns on perceptions of DMTs in subject matter experts and the wider public. Public perceptions of new technology tend to be an understudied area (Bellamy, 2019), but exploring the factors that shape perceptions may provide a valuable starting point for recruiting and training future digital manufacturing experts. This is especially important as technology acceptance research tends to focus on technology adopters, often with limited input from those that have not yet adopted a technology (Verdegem & De Marez, 2011). In a synthesis of five major technology perceptions models, Bellamy (2019) identified that beliefs about technology were a function of four multifaceted dimension: “knowledge of technology,” “project scope,” “impacts of technology,” and “trust in the control of technology.” Within the proposed framework, each dimension is associated with various aspects influencing positive or negative perception, such as the novelty of the technology, visibility, complexity, institutional trust, and users being “kept in the dark.” When considering the DMTs presented in the ContraVision videos, it is clear that each type would score highly on the aforementioned aspects: the videos portray them as having invisible, complex functions, which are not always transparent in how they work. With regard to technology impacts, aspects such as the distribution of risks/benefits, personal data privacy and personal data security were highly relevant in the current study. The use of personal data was a major point that came up from our study and influenced the perception and trust in companies collecting it. In summary, enhancing Industry 4.0 readiness is a complex topic, but integrating research into both organizational and social readiness may help to drive progress in this area.

4.2 | RQ2: Influence of portrayal of technology on attitudes

This study's second objective was twofold: first, it aimed to demonstrate the ContraVision technique's efficacy as an elicitation method within HFE research, and second, it aimed to identify how technology portrayal influenced attitudes toward it (RQ2). Previous work has shown that the ContraVision technique's use of opposing viewpoints can lead participants to generate a wide range of opinions toward the target technology, shaped by the viewpoint to which individuals were exposed (Mancini et al., 2010). Furthermore, the technique provokes thought on topics that may be difficult for participants to identify with due to a lack of prior experience. Here, this was due to the futuristic nature of the given scenarios and DMTs. Analyses comparing responses between participants in the utopic condition and the dystopic condition supported previous findings in this regard.

Given that the videos presented such different visions of the future, it was expected that a significant difference in opinion would be found between the two conditions. However, two aspects of the responses were particularly interesting to note: the distribution of the attitudes between Utopian and Dystopian conditions, and the questions for which there were no significant differences, despite descriptions in qualitative feedback. When probed on their attitudes toward the company and DMTs mentioned specifically in the videos, participant responses between the two conditions were significantly different. When asked how positive they would feel about working for such a company, participants in the dystopic condition responded highly negatively, as expected; however, while a symmetry in ratings for the utopic condition might have been expected, this was not the case, and the median ratings reflected only a slightly positive attitude.

This echoes the thematic analysis, which showed that even when presented from a utopic perspective, participants still held concerns over the misuse of such technologies.

A similar phenomenon was observed when participants were asked whether they would trust this company with their data. Again, as expected, those in the dystopic condition responded highly negatively while there was more of a uniform distribution across ratings in the utopic condition, with a median of 3, indicating a neutral attitude. These findings were also in line with the thematic analysis results for the utopic condition. Responses also revealed that when presented with the Dystopian view, participants slightly disagreed that the technologies in question would make their manufacturing job easier, but those exposed to the Utopian view believed the impact on their work would be largely positive. This indicates that the participants could see the benefits of these technologies despite the concerns that were communicated through the open-ended responses. In the thematic analysis, this is reflected by the "Positive outlooks for industry" identified subtheme, indicating that even in the dystopic condition, participants still saw some benefits of these technologies.

With respect to the individual DMTs demonstrated in the videos, the utopic versus dystopic portrayals also appeared to have influenced participants' attitudes toward them. When shown the dystopic perspective, participants held highly negative attitudes toward wearing physiological sensors at work, but they felt more favorably toward working alongside a robot and using distributed data technologies. Viewers of the utopic perspective participants felt significantly more positive toward each of the three technologies but notably still held some reservations. For example, utopic participant responses were skewed toward highly positive ratings toward the use of robotics and distributed data technologies. In comparison to the slightly more neutral dystopic participants, this may indicate that after seeing the scenarios, even participants in the dystopic condition saw some benefits of robotic technology, in line with the "Positive outlook for industry" subtheme found in the "Wider society" aspect of the thematic analysis. In contrast, portrayal type appeared to lead to different and meaningful identifications of concerns and challenges for the implementation of such technologies; this is seen in the uniform distribution of ratings across the scale toward the physiological sensors shown in the utopic video. Thus, even when these technologies are presented in a positive light, participants had concerns about the potential for misuse and tended to be cautious about trusting companies with the use of their data.

4.3 | ContraVision as a systems ergonomics method

Through this study, we have demonstrated the ContraVision technique to be an effective way to capture individual perceptions of technology, something that is of great relevance to HFE and in particular, systems ergonomics research and development. Traditional methods used in the design and evaluation of future technologies and systems often capture individual perceptions through questionnaires (Sandhu et al., 2020), workshops (Perez & Neumann, 2015), and semistructured interviews (Asplund & Nadjm-Tehrani, 2016). In addition, methods such as Cognitive Work Analysis (Salmon et al., 2016), Event Analysis of Systemic Teamwork (Walker et al., 2006), and Ecological Interface Design (EID) (Vicente & Rasmussen, 1992) have been widely used to analyze properties, interactions, and emergent behavior within complex sociotechnical systems to inform the design of future technologies.

Kant and Sudakaran (2022) proposed an extended approach to EID, the integrated EID (iEID), motivated by the need for novel design approaches for increasingly digital systems and validated this in the design of a digital twin. Within iEID, early-stage activities involve developing a conceptual model of the context of use, with the recommendation to capture data on the work domain, tasks, situations, and operator characteristics through qualitative analysis. It is in HFE endeavors such as this that we believe the ContraVision technique would have the most significant impact. ContraVision is a useful tool for exploring aspects of the design before a technology or system is fully realized, and as we have demonstrated through the questionnaire-based study, the design fiction can provide relatable narratives that provoke thoughts on a range of factors. As shown through the thematic analysis in particular, participants provided insight into attitudes toward the context of use and interactions within the fictional future manufacturing system, two aspects considered essential in the systems ergonomics perspective (Wilson, 2014). As the ContraVision films provided a holistic view of the DMTs, it is possible that this holism provided enough understanding for nonexpert participants to identify with, allowing them to think through complex design questions in meaningful ways.

4.4 | Limitations and future work

There were several aspects that limit the conclusions that can be drawn from this work, primarily related to sample size, sample demographics, and the nature of the data collection instrument. First, the study focused exclusively on attitudes held by residents of the United Kingdom, so the results may not generalize to other countries and cultures; indeed, previous research has shown that there are cultural and societal differences in perceptions of technology (Muk & Chung, 2015; Zubiaga et al., 2018). Second, the sample was skewed toward younger, highly educated participants, with little prior experience in manufacturing. Out of 134 participants, approximately two-thirds of the sample held an undergraduate or postgraduate degree and approximately 80% were under 50 years old. Future work should address this limitation by expanding the sample to represent the broader population. It is possible that this limitation was a by-product of the sampling methods used in the online recruitment platform, and in the future, studies should expressly seek out participation from a more representative sample to increase diversity among perspectives.

The nature of the online questionnaire also created a major limitation to the richness of the collected data. An online questionnaire approach was chosen so that it could be circulated among many participants while also reducing the need for face-to-face interactions during the coronavirus disease 2019 pandemic. However, as commonly experienced in other questionnaire-based studies, the open-ended data collected from participants were limited in depth. In addition, the sample size of responses to the open-ended questions was reduced, with only just under half ($N = 62$) of the entire sample choosing to respond. Alternative qualitative research methods, such as focus groups or one-on-one interviews, would be valuable in future studies of participant opinions and concerns surrounding DMTs, allowing for deeper insight past what questionnaire methods could provide.

5 | CONCLUSION

Digital technologies play an important role in modern lives, both in relation to leisure and work. The manufacturing industry stands to gain from digital technology, particularly the technologies included in the Industry 4.0 paradigm, a selection of which were explored in this study. We explored public perceptions of these futuristic DMTs through a novel application of the ContraVision technique, for which two parallel videos were created: a utopic and a dystopic view of a future where manufacturing workers regularly encounter such tools. The demonstration of the ContraVision technique showed that portrayal influenced participant attitudes toward the DMTs. However, in line with previous research, the thematic analysis revealed that while attitudes between the two portrayal conditions overlapped, the use of two viewpoints resulted in a broader, complementary range of feedback.

The thematic analysis of qualitative feedback makes an important contribution toward identifying a set of challenges for the development and implementation of DMTs in future workplaces. Participant feedback clearly indicated the need for secure, trustworthy systems that protect personal data rather than exploit it to the detriment of workers. Additionally, responses revealed the importance of clearly communicating the value of and potential benefits of DMTs while recognizing that different end-user groups may have different needs that must be understood and accommodated during the technology design and implementation process. Furthermore, participants in both utopic and dystopic conditions voiced concerns surrounding being forced to use technology to benefit the fictional organization but not the individual. This points toward risks with the balance between end-user engagement and satisfaction, and based on these results, we argue that implementation programs should consider whether tools and technologies serve the interests of both the employer and the employees, moving from a "technology for technology's sake" approach and toward a paradigm that considers and incorporates a diverse range of stakeholder values and feedback.

Second, based on this demonstration, we argue that the ContraVision technique offers a valuable framework for eliciting user feedback on technologies and systems that are difficult to interact with directly, something that complements existing HFE methods and is of value in systems ergonomics research. Although the future of manufacturing is unlikely to be either fully utopic or fully dystopic, by understanding and addressing societal concerns about these systems, we can provide direction to enable not only more productive and efficient workplaces, but also workplaces that are more equitable and acceptable to their workforce.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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