ROBOTICS AND THE IMPACT ON NURSING PRACTICE

Case Study and Pilot Site Analyses

MARI TIETZE & SUSAN MCBRIDE

ANA
AMERICAN NURSES ASSOCIATION

About the American Nurses Association

The American Nurses Association (ANA) is the only full-service professional organization representing the interests of the nation's 4 million registered nurses through its constituent/state nurses associations and its organizational affiliates. The ANA advances the nursing profession by fostering high standards of nursing practice, promoting the rights of nurses in the workplace, projecting a positive and realistic view of nursing, and by lobbying the Congress and regulatory agencies on health care issues affecting nurses and the public.

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Nurses of the Future: "What can be taken away that robots can absorb?"

—Dr. Liisa Ortegon, DBA, MAA-OD, BSN, RN, NEA-BC,
Houston Methodist Hospital,
Senior Vice President of Operations,
Chief Nursing Executive, and
Entity Business Practices Officer,
Wharton Fellow

In the future, robots may become as commonplace as today's automobiles, computers, and cell phones. Robots will be working in homes and offices; assisting in hospitals, classrooms, and factories; helping to run farms and mines; and exploring in air, on land, underwater, and in space. They will be helping the elderly and people with disabilities in their activities of daily living. They will be helping to perform mundane or dangerous tasks. They will be among the first responders at natural disasters, rescuing people in need and protecting humans from hazards. Teams of humans and robots, large and small, will reliably and efficiently cooperate, enriching the quality of life and work for individuals and society alike.

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DILIGENT ROBOTICS, INC.

We acknowledge the work of the team of inventors and engineers that contributed to the success of the case study of pilot sites. The team from Diligent Robotics, Inc. "build[s] robots that help people," especially nurses.

Diligent Robotics operates as a human-centered robotics company. The company develops autonomous hospital service robots to assist clinical staff with logistical tasks, which enables staff to spend time for direct patient care. Diligent Robotics serves customers in the state of Texas. The company was founded in 2017 and has an Austin, Texas contact address.
Sector: Industrials
Industry: Machinery
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Foreword

As natural innovators, it is no surprise that nurses are at the forefront of the adoption of one of the most disruptive technologies that will impact patient care, the robot. This white paper is a sign of our rapidly changing technological environment. The exploration of the use of service robots in the patient care environment is an important discussion for nurses to be involved in. Nursing, like many professions, will be impacted by the arrival of these robots. Whether the thought of robots in the patient care space excites you or repulses you, they are here to stay. Taking the time to think through how robots function, how the work environment will change, and how they will impact patient care, as well as nursing practice is important. It is also important that the information is shared with the broader nursing community.

Today, across the country, robots (powered by artificial intelligence) are being deployed and tested in inpatient care environments, so the proverbial "genie" is already out of "the bottle." While we can't go back in time to before robots existed, we can ensure that nurses have input into how robots are designed, developed, tested, and utilized in the patient care setting.

Robots assisting nurses in providing patient care is something with which technology can help us, not as a replacement, but rather as a force multiplier. It is important to understand both the functionality and limitations that service robots will bring to the patient care ecosystem. This paper is a deep dive into the impact of service robots and the benefits they bring to the care team. This paper does not evaluate the design and development of the technology, artificial intelligence, or robotics that can potentially supplement nurses in the care setting.

This work on the impact of service robots in the nursing environment only examines the impact of one type of robot. The history, as well

as the future, of this technology as an assistance to nurses, is uniquely positive. However, further study may be necessary to understand a more accurate picture of the impact of this technology on support roles that, in turn, will require additional upskilling and retraining. If nursing is to remain relevant, we must use our superpower of innovation and become proactively involved in charting the path for the adoption of this emerging technology, provide direction into what skills robots provide, and help determine how robots are incorporated into the patient care ecosystem.

We hope that you find this report useful and look forward to your thoughts.

Happy innovating!

—Bonnie Clipper, DNP, MA, MBA, RN, CENP, FACHE
Founder & Chief Catalyst, Innovation Advantage

Executive Summary

BACKGROUND AND RATIONALE

Robotics inpatient care will transform and very likely revolutionize the way we deliver care. Richard Booth notes, in an August 19, 2019 interview with nursing researchers, that it is not "if" but "when" this transformation will occur to support the delivery of nursing care (Booth, 2019). As such, the American Nurses Association (ANA) collaborated with Diligent Robotics, Inc. and two nursing informatics researchers to conduct a review of the literature and examine three pilot sites that implemented service robots to support nursing in their institutions. All three organizations involved had a common characteristic: the institutions' leadership and nursing staff spoke to the institutions' commitment to transformational and innovative solutions to support their nursing staff in delivering quality care. This paper will review the current state of the science in terms of robotics, particularly service robots, and examine the experiences of three pilot sites to examine themes across these sites as a case study. Finally, recommendations will be made as to how organizations can prepare to embrace not only the inevitability of robots supporting nursing care delivery but how the profession can embrace and capitalize on the future use of robotics in nursing care.

METHODS

The study's methodology included an extensive review of the scientific literature to investigate how robotics are currently being used to support nursing care. Three pilot sites that have implemented service robots were visited; qualitative data was collected from nurses, staff, and leadership; and nursing researchers were interviewed to examine the current state of service robots to support nurses. The review of the literature was the context within which the case study was investigated

and analyzed, and recommendations were made based on the information gathered.

KEY FINDINGS AND RECOMMENDATIONS

Important findings on the use of robotics to support nursing care are reflected in this white paper. Key findings indicate that robots can support and augment nursing care delivery and are well suited to high-repetition, low-risk tasks, but they can also be used to support quality and safety initiatives such as efforts to reduce fall risk in both the hospital and home setting. Efficient supply delivery, improved nurse productivity, increased time with patients, and a positive emotional response were key themes in the results of this review.

Recommendations for adoption, implementation, and evaluation strategies noted in the paper include using best practices for workflow redesign; developing evaluation strategies that include outcome, process, and balancing measures; and involving a full complement of all stakeholders. Stakeholders include the patient as well as the interprofessional team, including the vendor, nurses on the unit, patient care assistants (PCAs), supply chain management staff, and health information technology professionals. Nursing informatics specialists are well suited to support these advanced technologies initiatives.

The paper concludes with important considerations for nursing research and education to address such things as augmented care delivery models using robots and repetitive task management with robots used to deliver such things as supplies, linens, and admission kits. Additional considerations include the emotional response to robots of nurses, staff, patients, and family.

Finally, recommendations are made that include public policy at institutional, state, and national levels that considers such things as guidelines for delegation of tasks, i.e., what might be appropriate to delegate to a nonhuman actor, the robot, and what might be better suited to direct nursing care. The report reflects a seismic shift in nursing education, as noted by the National Council of State Boards of Nursing, to fundamentally rethink the education and preparation of nurses to accommodate these new innovations. It will be important to determine what level of competencies should be included in educational

preparation for nursing essentials at the undergraduate, graduate, and advanced specialty levels related to robotics and other advanced technology innovations. Important economic factors include such things as time savings and improved safety. With these recommendations and the findings from the pilot sites, literature review, and interviews, this white paper begins to lay a foundation for these discussions and further national recommendations to support the adoption and implementation of robotics to support care delivery in a positive manner for both nurses and patients. In essence, we learned from the case study that service robots demonstrated successful, supportive care service tasks and deliveries. However, they are not capable of delivering skilled nursing care, nor are they intended to replace nurses.

Keywords

Automation, Automation Research, Mobile Manipulation, Nursing, Nursing Robot, Patient Care, Robotics, Robotics Research, Robots with Tactile Arms, Service Robots, Social Robots, Workflow

Glossary

Terms	Definitions	Source
Automation Research	"Automation research emphasizes efficiency, productivity, quality, and reliability, focusing on systems that operate autonomously, often in structured environments over extended periods, and on the explicit structuring of such environments."	Robotics and Automation Society of the Institute of Electronics and Electrical Engineers Cited in Christensen, 2009, p.8.
Mobile Manipulation	Mobile manipulation involves a robot with an arm to reach, a gripper to pick up objects, and a mobile base to move.	Diligent Robotics Cited in Diligent Robotics, Inc., 2019., para. 6.
Nursing Robot	The ISO8373 specifically defines a nursing robot as "systems of mechanical, electrical, and control mechanisms used by trained operators in a professional health care setting that perform tasks in direct interaction with patients, nurses, doctors, and other health care professionals and which can modify their behavior based on what they sense in their environment."	International Organization for Standardization Cited in Frazier, Carter-Templeton, Wyatt, & Wu, 2019, p. 290
Robotics (Robotics Research)	"Robotics focuses on systems incorporating sensors and actuators that operate autonomously or semi-autonomously in cooperation with humans. Robotics research emphasizes intelligence and adaptability to cope with unstructured environments."	Robotics and Automation Society of the Institute of Electronics and Electrical Engineers Cited in Christensen, 2009, p. 8.
Robots with Tactile Arms	"Robots with compliant joints have become common in research and commercial products exist. Yet, relative to compliant joints, whole-arm tactile sensing (robot skin) for robots is rare and the technology is less mature.:	Georgia Institute of Technology, Healthcare Robotics Lab Cited in Kumar & Kumar Shenoi, 2016, para. 3.
Service Robots	"Service robots assist human users in day-to-day tasks."	Proceedings of the 29th International Conference on Automated Planning and Scheduling Cited in Jiang et al., 2019, p. 1.
Social Robots	"Social robots are designed to interact with people in a manner that is consistent with human social psychology. They are a particularly intriguing technology in health domains due to their ability to engage people along social and emotional dimensions."	Conference Proceedings of the Institute of Electrical and Electronics Engineers (IEEE) Cited in Breazeal, 2011, p. 5368

Service Robotics and the Impact on Nursing Practice

Case Study and Pilot Site Analyses

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INTRODUCTION

Robotics in the patient care setting will transform and will very likely revolutionize the way we deliver care. The International Organization for Standardization (ISO) specifically defines nursing robots as "systems of mechanical, electrical, and control mechanisms used by trained operators in a professional health care setting that perform tasks in direct interaction with patients, nurses, doctors, and other health care professionals and which can modify their behavior based on what they sense in their environment" (ISO/TC299 Robotics Technical Committee, 2012, p. 1). This definition contrasts with the application of service robots to support the work of nursing. Service robots assist human users in day-to-day tasks, for example, patient care delivery of daily routines as well as in monitoring patients. This paper will review the current state of the science in terms of robotics used to support nurses, particularly service robots, and examine the experiences of three pilot sites as a case study to inform the potential use of service robots for nursing. Finally,

considerations will be provided for how organizations can prepare to embrace and capitalize on robots to support nursing care delivery.

BACKGROUND

History of Robotics to Support Nursing

One of the earliest nurse robotics studies involved a social robot named "Pearl" (Pollack et al., 2002). Pearl was developed out of a collaboration between the University of Michigan, the University of Pittsburg, and Carnegie Mellon University with members from engineering, social sciences, and nursing (Pollack et al., 2002). This project, titled "Nursebot," was aimed at developing mobile robotic assistants for the elderly with two primary functions: (a) reminding people about routine activities such as eating, drinking, taking medicine, and using the bathroom, and (b) guiding them through their environment (see Figure 1). Although fairly successful, the project caused much discussion about robots replacing nursing. This is also reflected in a more recent 2017 study in which staff had ambivalence about sharing workspace with a robotic aid (Hebesberger et al., 2017). Others have indicated that the "robotic revolution happening in healthcare" is a threat to nursing practice (Pepito & Locsin, 2019, p. 106).

Figure 1. **Pearl in action at the Longwood Retirement Community, study site (Pollack et al., 2002)**

Challenges with the Health Care Delivery System

Health care challenges facing the nation include rapidly expanding aging populations, nurses retiring at unprecedented numbers, and nurse and physician shortages at a time when health care reform is moving into alternative payment systems (Buerhaus et al., 2017). The shortages of nurses are not isolated to the United States, with forecasts globally exceeding 12 million by 2035 (European Commission, 2019). One answer to these challenges is to adopt new and innovative technology solutions. The use of robots in health care represents an opportunity to support those who are delivering health care. Robots can be used to enable people with cognitive, sensory, and motor impairments; help people who are ill or injured; support caregivers; and aid the clinical workforce (Riek, 2017). As noted, this paper will examine how robots can support nurses and examine three pilot sites that implemented a service robot to offload tasks commonly done by nurses. We emphasize that there are different types of robots available to support patient care delivery; however, for this paper, we are focused on the specific future opportunities for service robots (Jiang et al., 2019).

The use of robots in health care represents an opportunity to support those who are delivering health care.

Robotics as an Answer to the Challenges

Due to the predicted nursing shortages worldwide, Kangasniemi et al. (2019) conducted an extensive review of the literature to examine how robots and automated devices could potentially offload and alleviate the workloads of nurses. Their findings are compelling, indicating that there has been an increased focus on the use of robots and automated devices in nursing care. The authors also identified areas of nursing care and tasks that could benefit from being reassigned to robots. These areas included medication delivery, automated patient monitoring, and a number of areas where robots could assist with nursing treatments. These areas involved auto-tracking systems to identify patients, automated devices to inject or infuse treatment, robots for patients' daily hygiene, and robots to help nurses manage physical tasks like turning patients. Outcomes in these studies included impact on working time and workload, measurement accuracy, safety for the nurse and the patient, as well as usability (Kangasniemi et al., 2019).

Some robots, including those with transport and manipulation capabilities, are also intended to be socially intelligent.

There is a distinction between robots that transport or deliver items within a hospital (medications, supplies, etc.) and robots that have an arm and thus can manipulate aspects of their environment. Some robots, including those with transport and manipulation capabilities, are also intended to be socially intelligent.

The terms "robotics" and "automation" have precise technical meanings. According to the Robotics and Automation Society of the Institute of Electronics and Electrical Engineers,

> "Robotics focuses on systems incorporating sensors and actuators that operate autonomously or semi-autonomously in cooperation with humans. Robotics research emphasizes intelligence and adaptability to cope with unstructured environments. Automation research emphasizes efficiency, productivity, quality, and reliability, focusing on systems that operate autonomously, often in structured environments over extended periods, and on the explicit structuring of such environments," (Christensen, 2009, p. 8.).

Jiang et al. (2019), note a fairly simplistic but useful definition of a service robot as robots that are "devices that interact with people and assist them in day-to-day tasks" (p. 1). They further differentiate service robots as unique in their approach to the steps of a task as a classical type of planning problem. The classical approach requires adopting a "closed-world assumption," presupposing that everything the robot could possibly need to reason about is already represented for the robot to perform. Note that, in most real-world service robot scenarios, like those that arise when interacting with people in offices or homes, such a complete list of options for the robot's performance is not likely (Jiang et al., 2019).

According to Riek (2017), one of the key insights learned about the use of robots in health care delivery (relevant to their use in nursing) are that robots help caregivers and the clinical workforce who are currently overloaded with high rates of work-related injuries. Riek

also found that in health care, most problems are complex, and there is no "one-size-fits-all" solution, meaning that every person, task, and care setting is different. As such, there is a benefit from robots that are capable of robustly learning and adapting on the fly. To be successful with the use of service robots, nursing teams of technologists, researchers, providers, and users must closely collaborate to ensure successful robotic adoption and implementation into practice and workflow (Riek, 2017).

To be successful with the use of service robots, nursing teams of technologists, researchers, providers, and users must closely collaborate.

LITERATURE REVIEW

Search Strategy and Exclusions

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) reflects an evidence-based minimum set of items for reporting in systematic reviews and meta-analyses and was used as a guide in this white paper. The Ebsco Host "All Databases" feature, which included databases such as CINAHL, Medline, and PubMed, was the source of searches. Keywords of "automat*" OR robot*" and "nurs* or "patient care" were used in the title field, along with "NOT" statements. Limiters were applied related to publication years, peer-review status, and English language. Further limiters were applied by review of 195 abstracts and then the full text of retrieved journals. Figure 2 depicts the flowchart details for the literature search. The resultant 25 articles were similar to the findings of a recent integrative review of the literature by Kangasniemi et al. (2019).

Current State of the Science on Robotics to Support Nursing

Two publications were released in 2018–2019 consolidating important research results from an extensive review of the literature examining 25 studies focused on the use of robotics and assistive devices to support nurses. The Kangasniemi et al. (2019) publication examined robotics and its use for nurses in a integrative review of the literature. The second publication by Carter-Templeton et al. examined the current state of the science in terms of research and technology developments (patent filings) to examine how and when robotics can be used to support nursing practice. (Carter-Templeton et al., 2018)

Robotics will benefit nurses and it will be important to determine the appropriate place to include robots in nursing care delivery."

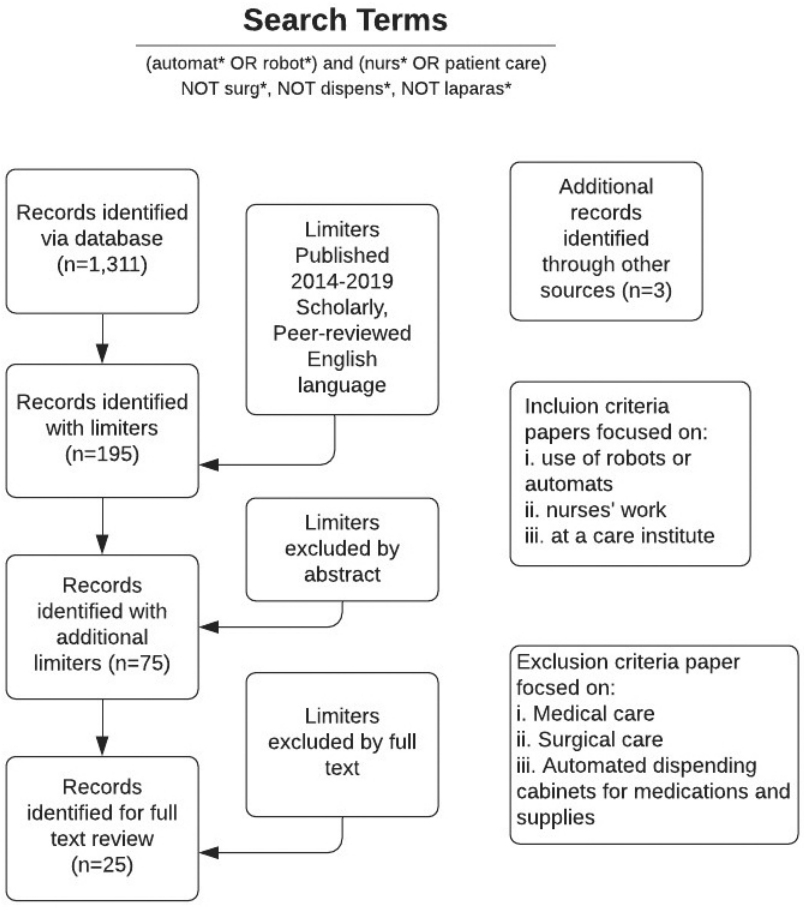


Figure 2. **Flowchart of the literature searches**

Carter-Templeton et al. (2018) conducted a study to examine patents filed with the United States Patent and Trademark Office. The investigators used a seven-step approach to four different databases, including the U.S. Patent and Trademark Office patent database, the U.S. Patent and Trademark Office patent application database, the European Patent Office database, and Relecura, a patent search and advanced intellectual properties analytics platform (Relecura Inc., 2020). Terms including "robots" narrowed down to patents germane to nursing care identified 878 items of interest. The main countries developing these technologies, in addition to the World Intellectual Property Organization (WIPO), included the United States, China, Japan, South Korea, and Taiwan. Growth is accelerating with the largest proportion of patents filed in 2016, the United States having the largest proportion at 26% (see Figure 3). Carter-Templeton et al. (2018) concluded that robotics will benefit nurses and it will be important to determine the appropriate place to

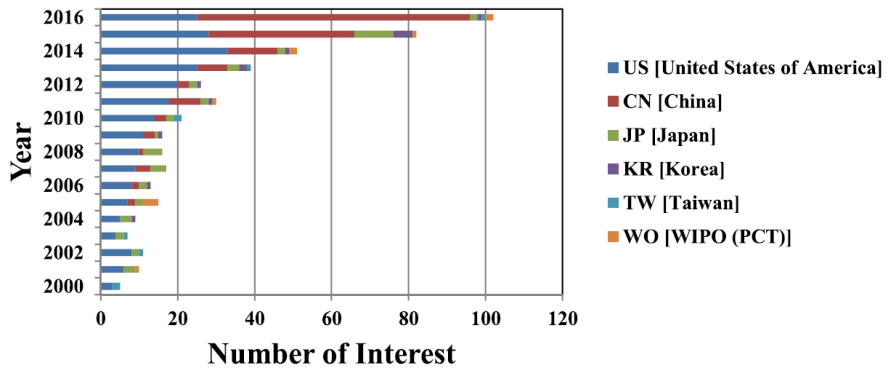


Figure 3. **Note the largest proportion of patents were in the U.S. Frazier, Carter-Templeton, Wyatt, and Wu (2018) reported the following statistics noted in the graph above U.S.=246, China=156, Japan=55, Korea=14, Taiwan=8, and WIPO=12. (Permission granted from CIN)**

include robots in nursing care delivery. Their study reinforces that it is critical for the nursing profession to help inform development, direction, and use of robots to support nursing care.

The extensive review of the scientific literature done by Kangasniemi et al. (2019) included 25 papers supporting the use of robots and automated devices to support nurses in delivering medication, monitoring patients, and providing nursing treatments. This review of the literature was global but restricted to journals published in English. From the authors review of the literature in Figure 2, specific to future innovations, on the next generation of robots we found very few that focused on nursing. This next generation of robots appears to be where the greatest opportunities lie for health care.

In countries such as Japan, the approach to nurse robotics is to use android robots that look like human beings. One such robot is ACTROID-F. This robot is modeled after a human female and can move its eyes, eyebrows, mouth, head, and neck. Actroid-F has the same body proportions as a medium sized-adult female, appears light-skinned, and has brown shoulder-length hair. Actroid-F is a telerobot that can be controlled by a remote operator, whose expressions and speech it can mimic very accurately. This robot looks and interacts with patients as a human. Some have indicated that the likeliness to a human is sometimes confusing to patients, making nonhuman like robots more appealing (Saenz, 2010).

In countries such as Japan, the approach to nurse robotics is to use android robots that look like human beings.

Emerging innovations such as artificial intelligence (AI) and robotics are poised to radically change nursing practice.

On the order of patient safety and quality, however, one very relevant recent study done by Coahran et al. (2012) examines the use of robots to detect accidental falls in a geriatric psychiatric unit. This study is particularly relevant to the pilot sites testing a service robot because one of the pilot sites evaluated the use of a service robot to support accidental fall prevention. The Coahran study and the observations from this study's pilot sites, reinforce the potential for service robots to support accidental fall prevention and associated patient safety initiatives (Coahran et al., 2018).

Emerging Innovations Coupled with Robotics

Emerging innovations such as artificial intelligence (AI) and robotics are poised to radically change nursing practice. One capability that has enabled an increasing number of applications is the ability for AI to safely navigate indoors around people. An example of this is warehouse logistics, where a warehouse for a company such as Amazon has robots that operate alongside human workers (Clipper et al., 2018). Lessons learned from warehouse logistics can likely inform the development of robotics for supply chain management in hospitals.

Another big advancement has been in voice recognition, as seen in products such as Apple's Siri, Amazon's Alexa, and Google's Home (Clipper et al., 2018) The advancement of AI can also be seen in the consumer market through the adoption of voice recognition devices. Speech recognition is now about three times as fast as typing, and the error rate has greatly decreased over the last several years, making this the favored approach for many purposes where speed or convenience is important (Clipper et al., 2018).

In terms of robotics and AI technology in hospitals today, many of the service robots do not have an arm (Clipper et al., 2018). They cannot manipulate the environment, for example, to open doors and cabinets and pick up individual items. So, ultimately, the last part of the task may fall on the clinical staff to accomplish. Once a robot has a functional arm, it can complete end-to-end tasks. Companies such as Diligent Robotics, whose Moxi robot has an arm, are developing "mobile manipulation robots specifically for such 'fetch and gather' nursing support tasks" (Clipper et al., 2018, p. 4).

The integration of robotics with electronic health record (EHR) systems presents a significant future opportunity for impacting health care delivery. Robotics will be able to use information contained in the EHR to automatically assist nursing staff, for example, by obtaining certain supplies, equipment, and medications to the point of care delivery (Clipper et al., 2018). Eventually, similar integration with mobile or wearable devices used by nurses or patients, along with machine learning and AI, will make health care delivery more efficient, effective, and safe.

The integration of robotics with electronic health record (EHR) systems presents a significant future opportunity for impacting health care delivery.

Future Trends and Economics

Adoption factors. Key factors to the success of robotics use in health care have been centered on the adoption of the technology from a care provider aspect and a patient aspect. Thus, where robotics use in health care is promising, the adoption process necessitates a multifaceted approach. According to Riek (2017), robotics implementation teams must pay attention to five foundational adoption factors:

1. Safety and reliability. Safety testing and confirmation of reliability before implementation are a major success factor for robotic adoption.
2. Capability and function. Associating the robotic capability and function to the actual needs of the end-user are a critical alignment.
3. Cost-effectiveness. Robotics is in a high-cost category; therefore, along with implementation, a plan for calculation of postimplementation cost savings is needed and should be sustainable.
4. Clinical effectiveness. As with any care-delivery approach, measurement of resultant outcomes is necessary including process, outcome, and balancing measures.
5. Usability and acceptability. Not only is usability important, but the user and patient acceptability is equally important (Riek, 2017).

Challenges and Barriers to Address for Robotics Adoption. Rogers's technology adoption life cycle is particularly relevant to robotics in health care. Rogers outlines five stages of adoption: innovators, early adopters, early majority, late majority, and laggards (Rogers, 1962). Clearly, all three pilot sites described in this paper are early adopters and innovators of

There are significant opportunities for improving the safety, quality, and efficiency of health care through robotics.

service robots to support nursing. As we think about how to support the health care delivery system in the adoption of robots, we need to consider this cycle and how to address barriers that often impact the adoption cycle.

An additional consideration with the adoption of any new technologies to support clinical care is how the technology might inadvertently create unintended consequences (Sittig & Ash, 2011). While extensive work has recently looked at the EHR in terms of unintended consequences, there are also cautions related to robotics.

A study conducted by Cresswell et al. (2018) addressed challenges with adoption. The study aimed to understand the emerging role of robotics in health care and identify existing and likely future challenges to maximize the benefits. The study included semi-structured, one-to-one interviews exploring the role of robotic applications in health care contexts, with those who developed the robotics as well as those who used them. Twenty-one interviews were conducted, and these accounts suggested that there are significant opportunities for improving the safety, quality, and efficiency of health care through robotics. However, the study also identified barriers with the potential for errors and misuse of robots. These four barriers should be considered for effective innovation and to support the technology adoption cycle for robotics:

1. A clear demand from professionals and patients
2. Appearance of robots and associated expectations and concerns clinicians may have
3. Disruption of the way work is organized and distributed (resistance to change or workflow considerations)
4. New ethical and legal challenges requiring flexible liability and potentially new ethical frameworks (Cresswell et al., 2018)

Balance of Technology and Caring. Robotics to support nursing calls for a new examination of models of nursing care delivery updated to reflect the massive amount of technology being used. According to Locsin (1995), the concepts of technology and caring within the context of competencies for nursing care delivery illustrate the realities

of advancing technologies in health care. Locsin (2005) states, "[T]he practice model that is crucial to contemporary nursing is one where the practice of caring in nursing can be expressed through technological competency" (p. 6). The ingredients of technological competency include the concept of humans as unpredictable, whole, and complete in the moment. According to a more recent publication by Locsin (para 1) (2018). "Nursing is a discipline of knowledge and a practice profession grounded in the ideal value of nursing as integral to human health care and well-being." In the area of robotics and technology, nurse competencies should be focusing on the use of robotics while continuing to maintain the caring components of the nurse-patient relationship. This approach aligns with patient-centered models of care that are important to consider as we amass more and more technologies to support the delivery of care.

The marketplace for health care robotics is booming.

Broader Market Place of Health Care Robotics

The marketplace for health care robotics is booming along with prediction analysis, machine learning, and artificial intelligence growth trends (Carter-Templeton et al., 2018; Fareed, 2017; Georgia Tech Institute of Technology, 2020). Robots allow for these three analytic functions to be contained within a computer-like technology that is mobile and is placed where these functions are best deployed, with the patient and the patient's caregiver. The market for health care service robots is of interest in this paper. Some of the top suppliers of such products are listed in Appendix A, along with their key characteristics.

Robots used in the health care industry have been categorized for the types of services delivered. Some categories identified by Dr. Fareed of Cerner Corporation are listed here (Fareed, 2017).

Surgical robots: This technology assists in various surgeries that require small, precise incisions, giving surgeons a greater amount of control over the procedure and helping them work more accurately. Other robots can offer more exact bone cuts with a minimized amount of ablated bone and soft tissue damage, which promotes faster healing.

Pharmacy robots: Robots can read information sent from hospital information systems and update the dispensing status of prescribed drugs. A robotic arm can attain the appropriate vial or packet, then collect and label the medication. Using barcodes to verify medication, robots can also package, store, and dispense filled prescriptions. Robots can also assist in the preparation of intravenous (IV) solutions.

Robotics in rehabilitation medicine: Exoskeletons are wearable robotic structures that can help humans with their range of motion. They are often used for rehabilitation therapy procedures, such as gait training to help patients with paralysis walk again and limb mobilization and guidance for patients recovering from a stroke. Patient-specific parameters, like the amount of force used and range of motion, are tracked by these machines and can help customize treatments based on an individual's progress. Some robot-assisted therapies facilitate better patient outcomes with faster recovery, and they also provide a precise way to capture and measure valuable patient data.

Robots in telemedicine: The need for telemedicine is driven out of a shortage of health care professionals and the unavailability of specialized care in remote areas. A version of telemedicine is a human-sized telerobot featuring audio, video, and camera technology designed to facilitate patient monitoring, timely communication, specialized patient care, and even high-quality emergency consultations. Other notable benefits include data tracking and access. Robots enable clinicians to remotely log in, review patient data, and communicate with the patient and other care team members.

Mobile logistics robots: In a typical hospital setting, there are many items to be transported daily, including thousands of medication orders, meal orders, linens, and pounds of trash. An autonomous mobile transport robot can be used for many of these tasks, helping to reduce wait times and staff workload. These robots can navigate freely across the hospital using sensors (Fareed, 2017). This is the category most like Moxi, the Diligent Robotics service robot.

Carebots: Carebots are robots designed for use in home, hospital, or other settings to assist, support, or provide care for the sick, disabled, young, elderly or otherwise vulnerable persons (Vallor, 2011, p. 2). Sharkey and Sharkey (2010) note that tasks often delegated to care robots can be classified into several areas including: 1) providing assistance in caregiving tasks, 2) monitoring a patient's health status, and/or 3) providing social care or companionship.

Moxi was created to support health care workers, such as nurses, in their patient care delivery activities.

As noted, this paper includes a case study of three pilot sites using service robots. A description of the pilot sites, methodology, and findings are presented in the following section.

METHODOLOGY AND CASE STUDY OF PILOT SITES

Methodology

In addition to an extensive review of the literature, methods were developed by two nursing informatics researchers to collect, consolidate, and analyze data and information from each of the pilot sites that implemented the service robot Moxi. Moxi was created to support health care workers, such as nurses, in their patient care delivery activities. It is considered a mobile-manipulation-type of robot with an arm to reach, gripper to pick up objects, and a mobile base to move (Diligent Robotics, Inc., 2019, para. 6).

To promote consistent data collection for the study, a data collection template was used by the participating organizations to report demographics and study implementation details. Information was also collected from Diligent Robotics of how the vendor mapped important tasks and the approach the institution elected to take with their customized pilot use of the service robot at each site. For example, one of the organizations elected to conduct an IRB-approved research protocol, whereas the other two approached the project from a technology implementation standpoint using a quality improvement approach to their pilot of the service robot. The company honored both approaches to the adoption and implementation of the service robot to inform further refinement and development of Moxi for the support of nurses.

These site visits allowed for the collection of qualitative data on the perspectives and experiences of health care professionals using service robots.

The researchers also made on-site visits lasting approximately six to eight hours for interviewing nurses, patient care assistants, and nursing leadership. These site visits allowed for the collection of qualitative data on the perspectives and experiences of health care professionals using service robots.

Questions to inform these qualitative data included the following:

1. Please tell me about your experiences with Moxi.
2. Please describe how you used Moxi.
3. What has worked well for you?
4. What has not worked well for you?
5. How has Moxi impacted the nursing care on the unit?
6. Is there anything else you would like to tell us about your experiences with Moxi?

Questions to generate quantitative data were included to support the measurement of improvements in productivity, efficiency, and cost. These are extremely important in advancing this service robotics technology.

- What time savings, if any, were noted?
- What supply cost savings, if any, were noted?
- What equipment cost savings, if any, were noted?
- What changes, if any, for time spent with the patients were noted?

Qualitative textual comments were examined for trends in positive, neutral, and negative comments about the staffs' pilot study experience overall.

Case Study of Pilots in Multiple Sites

This paper outlines important pilot site experiences, examining the experiences of these institutions using case study analysis methods recommended by Yin (2019). It is common for case studies to include cases from separate locations (Yin, 2009). Sites self-selected working with Diligent Robotics. The company has created a service robot called Moxi (see Appendix A). This paper reports the findings and results of the experiences of these three pilot site locations using a service robot to support nursing units. The case study to examine three

pilot sites was conducted sequentially and took place over the course of 12 months. The first site to pilot the Moxi robot was Texas Health Presbyterian Hospital in Dallas, Texas (PHD). The second hospital was the University of Texas, Medical Branch (UTMB) in Galveston, Texas. The third hospital was the Houston Methodist Hospital (HMH) in Houston, Texas. Each site was chosen because it was known for having an innovative culture and a willingness to test a service robot. Their proximity to the corporate office of Diligent Robotics in Austin, Texas, was also a factor.

Each institution worked with Diligent Robotics to identify important workflows and tasks that either related to the research questions or were identified areas for quality improvement on the specific units.

Description of Case Study Pilot Sites, Workflow, and Tasks Undertaken by Moxi

Description of Pilot Sites. The case study pilot sites had many common characteristics in terms of unit bed size, designated Magnet status, location in hospitals within large health care systems, and deployment of Moxi on similar nursing units. There were also differences in terms of the tasks that were trialed at each institution. The following is a summary of the tasks at the three pilot institutions.

At each site, Diligent staff worked closely with project leadership, including executive-level administrators, the unit manager, and clinical staff on the unit, to identify the most valuable set of support tasks and workflows to be trialed. Table 2 highlights the demographics of each of the institutions. See Appendix B for more details.

One of the institutions had a remarkably larger total bed count (1,403) than the other two; however, the average daily census for all three hospitals was similar, ranging from 500–826. All three institutions had gained Magnet status. Two of the units elected to implement Moxi on medical-surgical units, whereas the third unit did so in a neurology-specialty medical-surgical unit.

Workflow and Tasks Undertaken by Moxi at Pilot Sites. Each institution worked with Diligent Robotics to identify important workflows and tasks that either related to the research questions or were identified areas for quality improvement on the specific units. The final set of support tasks trialed at each hospital were similar in terms of how Moxi could support nursing and staff on medical-surgical units but differed as to how the tasks were undertaken. Each institution and the specific

Table 2. **Demographics of pilot sites for service robot**

Demographics for the Three Pilot Sites							
Name	Beds	Average daily census	Academic/ teaching facility	Magnet status	Type of nursing unit	Beds	Employee count
Texas Health Presbyterian Hospital in Dallas, TX	898	821	no	yes	Neurology	21	40
University of Texas Medical Branch in Galveston, TX	561	500	yes	yes	Medical-Surgical	16	43
Houston Methodist Hospital in Houston, TX	967	826	yes	yes	Medical-Surgical Telemetry	20	35

nursing units worked with the vendor to customize the workflow, taking into account the physical space of the unit. Additionally, the way in which they elected to deploy Moxi differed. For example, one institution elected a quality improvement strategy to address accidental fall prevention, whereas another hospital had a full research protocol to adopt, implement, and evaluate Moxi. Tasks for each site are outlined below.

Tasks that were trialed at THD.

1. Moxi delivered an admission kit along with suction setup and (if needed) a telebox (a metal box outside the patient room where Moxi delivers items) to each newly cleaned patient room.
2. Moxi delivered water bottles for patients twice a day, ahead of medication times.
3. Moxi removed soiled linen bags that were placed outside patient rooms at set times during the day and night shift and took them to the soiled utility room.
4. Moxi took specimens collected on the night shift and all day on the weekend down to the lab, inside a lockbox that was affixed to the robot.
5. Based on patient information available in de-identified Epic reports, Moxi assembled and delivered kits of supplies needed for specific clinical care tasks, delivering supplies to the specific room number.

6. Moxi delivered the following: a peripheral IV re-site kit, specimen collection kits (urine, sputum, stool), a blood draw kit, central-line dressing change materials, a feeding-tube change kit, and wound care supplies.

Tasks that were trialed at UTMB.

1. Moxi delivered an admission kit to each newly cleaned patient room.
2. Moxi delivered a clean set of linens outside of each patient room daily.
3. Moxi removed soiled linen bags that were placed outside patient rooms at set times during the day and night shift and took them to the soiled utility room.
4. Moxi delivered a set of daily essential supplies to the drawer outside each patient room (saline flushes, gauze, bandages, alcohol prep pads), replenishing daily as needed.
5. Moxi stocked convenience caddies with supplies needed for registered nurse (RN) blood draws nightly.
6. Moxi monitored periodic automatic replenishment (PAR) levels for a target set of items in the unit supply room, retrieved items needed to bring the unit to minimum PAR, and restocked the items.
7. Each morning at 7:30 a.m., for any of the supplies that were not at their minimum PAR level, an email was sent to Materials Management requesting the necessary items to bring the unit up to minimum PAR levels for these items. About an hour after the request was sent, Moxi traveled down to Materials Management to collect the supplies and deliver them back to the supply room on the unit.

Tasks that were trialed at HMH.

1. Moxi delivered an admission kit to each newly cleaned patient room.
2. Moxi delivered a clean set of linens outside of patient rooms, replenishing daily as needed.

The pilot project team worked with a nursing informatics specialist at one of the institutions to develop the specifications for the interface.

3. Moxi delivered a set of daily essential supplies to a "mailbox" outside each patient room (flushes, curos strips, redtops, gauze, bandages, alcohol prep pads), replenishing daily as needed.
4. Based on a de-identified Epic report pushed to Diligent every 30 minutes that included each patient's most recently documented fall risk status, Moxi delivered fall precaution supplies (slippers and fall risk bracelet) for each patient whose status changed to moderate or high.
5. Based on the same Epic report, each time a patient's fall risk status changed, Moxi visually scanned the fall risk sign outside the patient's door and verified whether the sign matched the patient's most recently updated fall risk status in Epic. An Epic report was pulled that supported Moxi and technical staff in aligning fall risk status.

In addition to these tasks, Diligent worked with the director of supply chain management at HMH to define and carry out a scoped trial of utilizing Moxi to retrieve one-off supply requests from central supply. During an in-person meeting within the planning phases of the trial, the director noted that reducing the time it takes his department to deliver these requests was an ongoing strategic goal for his department. This task was trialed on five separate days during weeks three and four of the trial.

Additionally, health information technology and nursing informatics helped to inform how the EHR could be interfaced with the robotics device. This was not accomplished during the pilots, but all three institutions noted it was an opportunity as well as a requirement for future implementations. The pilot project team worked with a nursing informatics specialist at one of the institutions to develop the specifications for the interface. A report was run and tested at two of the institutions, further refining interface strategies for future implementations.

Workflow Redesign for Robotics Adoption and Implementation.

Workflow considerations for nursing units are important to consider when implementing new and innovative technologies, such as service robots. The Agency for Healthcare Research and Quality defines workflow as "the sequence of physical and mental tasks performed by various people within and between work environments. It can occur at several

levels (one person, between people, across organizations) and can occur sequentially or simultaneously" (Agency for Healthcare Research and Quality, 2014, para. 1). It is essential to consider workflows in current states and future states when you elect to adopt and implement new technologies.

The Agency for Healthcare Research and Quality defines workflow as "the sequence of physical and mental tasks performed by various people within and between work environments.

Workflow redesign is particularly relevant to robotics in support of nursing tasks, as noted above. For example, in order to redesign workflows for UTMB and provide clean linens and essential supplies, tasks had to be explicitly mapped out on the unit in order for Moxi to be programmed to support nursing services in the delivery of clean linens. In addition, it was critical to fully standardize how things were done related to linen and supply delivery. Figure 4 reflects Moxi's workflow visually to show how the tasks flowed on the unit in order for Moxi to keep clean linens and essential supplies readily available. Moxi is depicted delivering a clean admissions kit (bucket), carrying the kit on its tray. Daily clean linen delivery required a hook on the door so that Moxi could deposit the clean linen outside the patient's room on the door, making it readily available to the patient care attendant. Moxi would then pick up soiled linen and take the soiled linen to deposit it in the dirty linen area. Essential supplies were delivered in a drawer noted in Figure 4. Moxi could open the drawer and deposit needed supplies. Further, Moxi is shown enroute to pick up low stock supplies from materials management, saving precious time and steps for nursing and PCA staff.

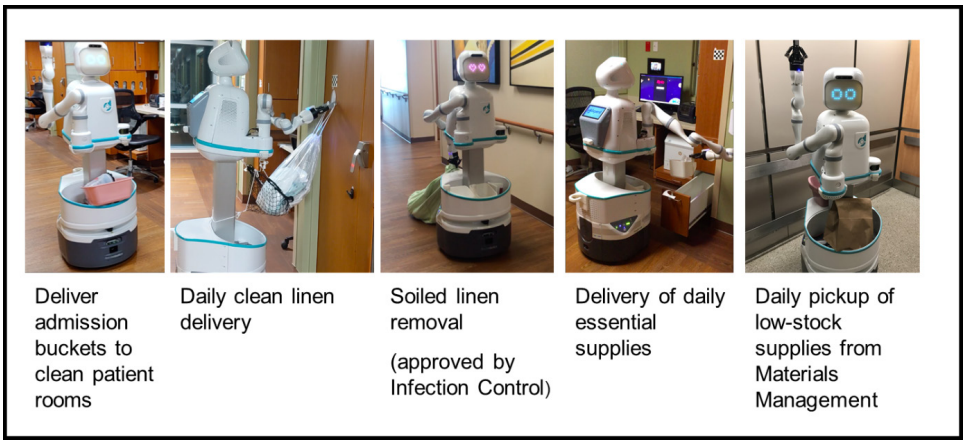


Figure 4. **Moxi's workflow for linen tasks and daily essential supplies at UTMB**

HMH staff created, and Diligent engineers programmed, two workflows: one for "Patient Safety Fall Risk" and a second for "Supply Delivery."

Workflows consider who is doing what, when, where, and how. For example, Moxi's evaluation trial at UTMB addressed the following:

Who: Staff and patients
What: Moxi as an assistant supporting the clinical team
Where: Jennie Sealy Hospital, unit 9C, medical-surgical nursing unit
When: Monthlong evaluation trial, January 21 to February 15, 2019

Workflow and Data Flow Considerations. Consideration as to precisely how Moxi was to support the clinical team was determined, and workflow was mapped to take into consideration routine fetch and delivery of items such as the exchange of clean and soiled linen and the delivery of admissions kits to clean rooms, as well as cross-unit delivery to various departments (e.g., pharmacy, lab, and central supply). The health information technology department, including important input from a nursing informatics specialist, helped determine how the EHR might trigger supply demand, such as with a patient admission or with blood draw for lab testing. While this pilot did not include an EHR interface, workflow and data flow mapping occurred in order to determine what type of data Moxi might be able to receive through EHR interfaces so that supply and demand for patients could be met on a timely basis without human communication required.

HMH staff created, and Diligent engineers programmed, two workflows: one for "Patient Safety Fall Risk" and a second for "Supply Delivery." The workflow mappings matured further with this pilot study to use Moxi to support patient safety fall risk as well as supply delivery tasks. For example, within 30 to 45 minutes of the EHR updating the accidental fall risk, Moxi was to change the fall risk status on the outside of the patient's room. Figure 5 reflects Moxi's updates to the fall risk on a unit at HMH. Figure 6 reflects the workflow of Moxi delivering supplies to a clean room ready for a new patient admission. Additionally, at HMH, special boxes were constructed such that Moxi could open the box and deposit daily patient care wish list items identified by nursing staff.

At PHD, on the other hand, it was the charge nurses who took control and organized the unit's work of the day. This was a good example of

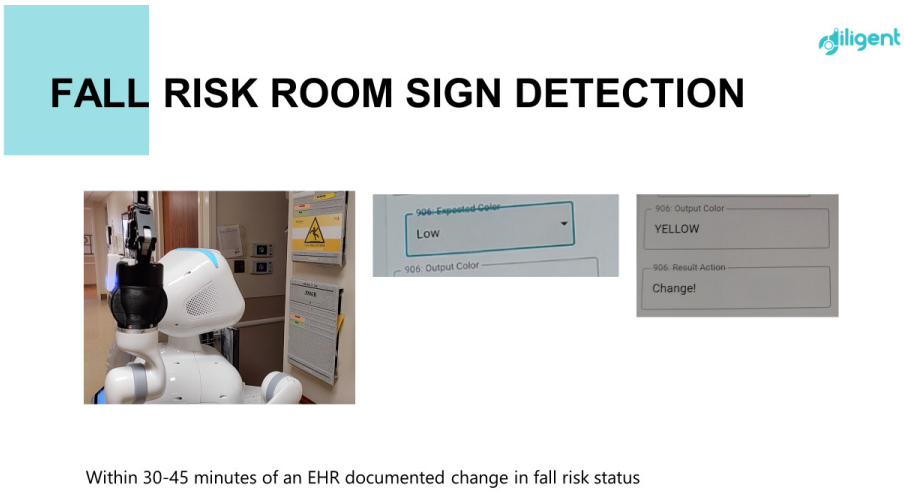


Figure 5. **Moxi's workflow updating fall risk per EHR updates**

Figure 6. **Moxi's workflow delivering admission supplies to a clean patient room**

how the role of nurses changes and evolves when you introduce robotics. As needed, forms were created collectively by charges nurses at this pilot site to optimally coordinate the "nursing/Moxi" care tasks needed for each patient on the unit each day. By the end of the pilot study, two forms had been created and put into daily use as follows:

- Appendix C "Charge Nurse Shift Report by Major Activity" is an example of the overall shift report that was provided each shift to the engineers for Moxi.
- Appendix D "Charge Nurse Shift Report by Patient" is an example of the specific shift report that provides information each shift about the unique procedure and supply needs of each patient and their room number.

These questions were aimed at collecting each individual staff member's experience using the Moxi robot.

Based on the content of these two forms, the Moxi engineers would then program Moxi to take care of those needs by providing the supplies at the correct times, for example.

Data Analysis and Interpretation

Two sources of data existed for the study: a) data collected using the case study template the authors created and b) the structured interview data. The case study template form was completed by team members of each study site. It covered basic demographics of each of the institutions, where they elected to implement and test Moxi, an opportunity statement, the study design, the study population, the study methodology, data analysis, a summary of findings, barriers/enablers, and the impact on nursing care delivery. In addition to the case study template, a structured visit agenda was established for the on-site visits by researchers (see Appendix E).

Results: Qualitative Data. During the on-site visit by each researcher, a series of structured questions were asked of the staff and/or the staff completed the form themselves. These questions were aimed at collecting each individual staff member's experience using the Moxi robot. From the three pilot sites, 119 comments were collected and analyzed for thematic content. Theme categories were identified where commonality of comments existed and yielded 33 theme categories. These theme categories are listed in Appendix F, along with sample representative comments.

As noted in Appendix F, the 33 theme categories of staff comments were summarized as either positive or neutral/negative. Table 3 depicts the frequency distribution of 33 theme categories where, for example, the most frequent theme category was "Positive Impact/Performance" (21.2%), while the most infrequent positive theme categories were "Public Relations Impact" and "Newly Found Extra Time," each with 3.0 % frequency.

Since these staff members were experiencing a pilot study, much of the neutral/negative comments are about potential "improvements" for any future pilot studies (18.2%), such as the need to have an interface to the EHR. "Physical Space Management" issues such as rate and accuracy of travel and avoiding bumping into Moxi during travel, comprised

Table 3. **Frequency percent for each of the theme categories**

Positive or neutral/neg	Themes category	Frequency percent
Positive	Positively Impact/Performance	21.2
Neutral/Neg	Pilot-Based Potential for Future	18.2
Neutral/Neg	Physical Space Management	6.1
Neutral/Neg	Safety impact	6.1
Positive & Negative	Supply Impact	6.1
Positive	Emotional Response to Pilot/Moxi	6.1
Positive	Basic Patient Needs	6.1
Positive	Patient/Family Perspective	6.1
Positive	Public Relations Impact	3.0
Positive	Newly Found Extra Time	3.0
Neutral/Neg	Comparison to Nursing	3.0
Neutral/Neg	Emotional Response to Pilot/Moxi	3.0
Neutral/Neg	Importance/Need for Workflow Knowledge	3.0
Neutral/Neg	Neutral-Negative Impact/Performance	3.0
Neutral/Neg	Patient/Family Perspective	3.0
Neutral/Neg	Staff Perspective	3.0
Total Sum		**100**

Note. Details of these theme categories and associated comments are provided in Appendix F.

The most infrequent positive theme categories were "Public Relations Impact" and "Newly Found Extra Time."

the next most frequent neutral/negative category, "Physical Space Management" (6.1%). Other neutral/negative comments were low in frequency (3.0%) and focused on Moxi's inability to care for a patient, such as taking vital signs. Other low-frequency categories were "Importance/Need for Workflow Knowledge" (understanding the nursing unit work dynamics), "Neutral-Negative Impact/Performance" (thinking "I can do it faster than Moxi") and "Staff Perspective" (fears of being replaced by a robot).

One theme category, "Supply Impact" (6.1%), reflected both positive and negative dimensions. This occurred because one pilot study experienced a savings in linen supply use, whereas the other experienced an increased expense. The details of workflow indicated a difference, for example, in the placement of the linen by Moxi when preparing for a patient admission to the nursing unit and/or for daily linen changes. When the linen was placed in the room but then not used, an expense occurred. Whereas, when the linen was placed in a protected location outside of the room and could be used again, the lack of use did not

Emotionally, having Moxi around was a positive for both staff and patients/families.

result in an expense. Simple workflow adjustments could rectify the issue.

In general, the positive comments that described opportunities seemed to be more homogenous than the neutral/negative comments. Those comments about the pilot study centered around two themes, the emotional aspect and the productivity aspect. Emotionally, having Moxi around was a positive for both staff and patients/families. For example, there was mention of being "proud to be selected as the nursing unit for testing of this new robotics technology." Common positive productivity comments were about the basics for care delivery, such as consistently having water available at the bedside and consistently having critical supplies such as IV flushes in the patient rooms. The impact on workflow related to patient admission and discharges was a consistent theme. The positive aspect of having extra time for the nurse to care for the patient was a welcome experience and "took some getting used to." Most nurses indicated that they used the extra time to educate and to prepare the patient for discharge.

A summary of the opportunities for service robots is reflected in Figure 7. Key themes noted in the pilot studies are improved supply

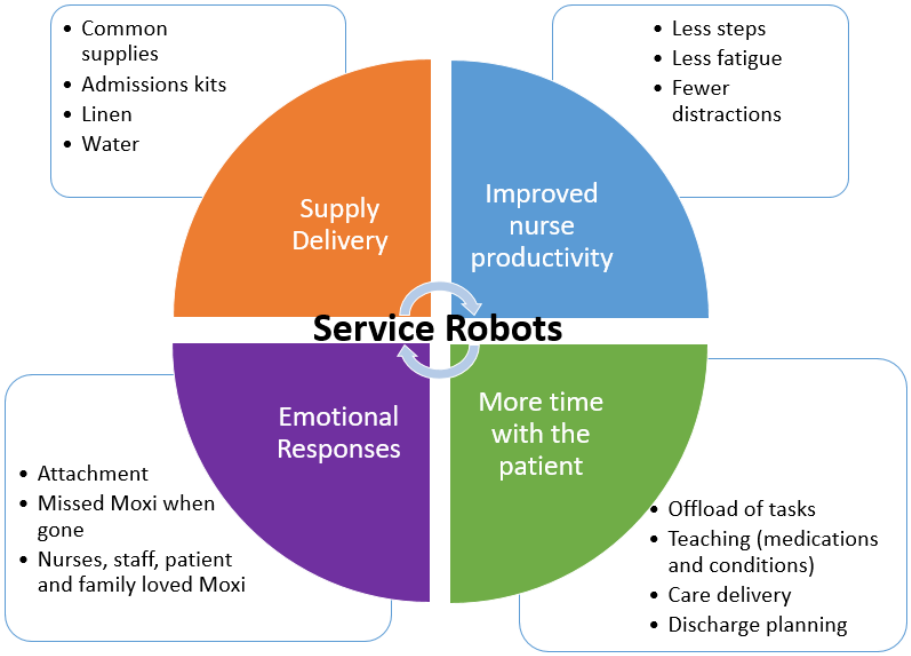


Figure 7. **Opportunities for service robots to support nurses**

availability, improved nurse productivity, emotional responses, and more time with the patient. While Moxi was a pilot for these institutions, the nurses, staff, and leadership clearly articulated how new possibilities could maximize the use of technologies to support and potentially augment nursing care through the use of service robots.

Moxi ensured 100% compliance that room signs matched EHR status within 30 to 45 minutes of a documented change in fall risk status.

Results: Quantitative Data. Findings from the individual sites varied in terms of what was collected and what would constitute quantitative data. HMH reported significant overall growth in average deliveries and in the average daily wish list items used per day across four weeks. Wish list items were those items identified by stakeholders as important items for Moxi to delivery on the unit. Figures 8 and 9 depict growth over the four-week period Moxi was on the unit.

Another important finding at HMH was an improvement in fall risk status. The institution reported that Moxi ensured 100% compliance that room signs matched EHR status within 30 to 45 minutes of a documented change in fall risk status. In the case of Moxi use for fall risk updates, Moxi also provided data analytics for fall risk assessment that

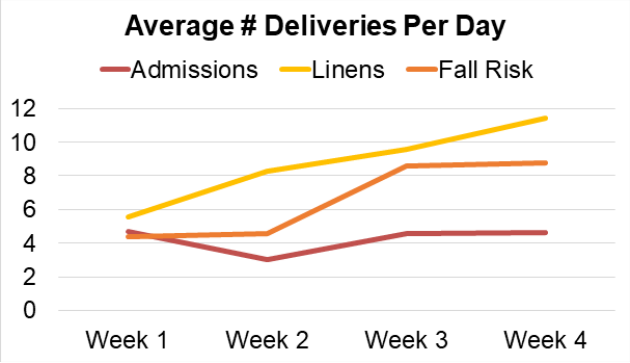


Figure 8. Average deliveries increasing over time

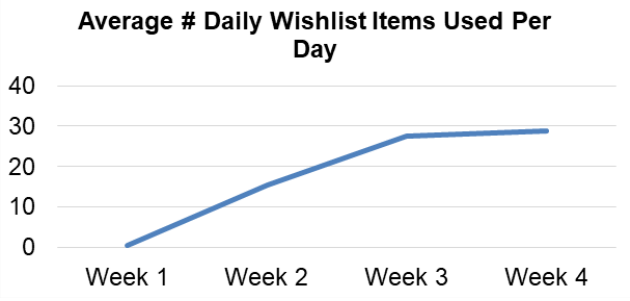


Figure 9. Change in counts per week

Dr. Booth looks at robotics and technology through the lens of the actor-network theory and suggests that it is important to define what we mean by robot.

can potentially serve as a tool for nursing leadership to identify clinical and educational opportunities.

IMPLICATIONS FOR NURSING PRACTICE

To explore implications for nursing practice, we identified two nursing researchers who were currently conducting research on the development and utilization of robots to support nursing. These researchers were individually interviewed to gain their perspectives on the future of robotics for nursing care. Specifically, these researchers provided their subject matter expertise on how robotics may influence nursing practice in the future.

Interview with Robotics Nursing Researchers

Dr. Richard Booth's Findings with Robotics Research. We conducted an interview with Dr. Richard Booth, from the University of Western Ontario, Canada, on August 19, 2019 (Booth, 2019). Dr. Booth related that his research started after he brought a robot into his home and his four-year-old daughter immediately befriended the robot. He laughed and described how dinners were disrupted because his daughter would be talking to the robot. He also indicated that she missed the robot and cried when he took the robot back to his office. He determined at that point that this social interaction warranted research attention. He realized the potential for robots to support nurses, but also recognized ethical considerations.

Dr. Booth looks at robotics and technology through the lens of the actor-network theory and suggests that it is important to define what we mean by robot and to consider the robot in terms of an automated process. Booth indicated that ideal areas where nursing should consider the use of robotics support would be high-repetition low-skills tasks. Exploring these areas is fruitful to consider because they minimize the risk that could occur in more care-oriented modalities. He further indicated that process optimization and long-term impact are important to consider.

Booth indicated we have been offloading tasks for years that nurses have historically done to create efficiencies and more productivity for

nurses. For example, we have expanded roles of PCAs and delegated many nursing care functions to PCAs under the supervision of professional nurses. Now, we are considering what tasks we can offload to robots. It is important to consider what roles will be disrupted due to this change of offloading tasks and potentially displacing humans. Booth notes that fear is often engendered by nurses when we discuss such things.

Booth emphasized the importance of nursing leadership as we consider the question of whether nonhuman actors (robots) will potentially displace humans to support care delivery. Booth used transportation as an analogy of how we can think openly about the use of robotics and how it will impact the future of nursing. For example, he noted that historically a vital source of transportation was the horse and buggy. Then, combustible engines came along and completely changed the way we use transportation, and all of the types of things we needed, such as livery stables, horse carts, roads, etc., had to change to accommodate the automobile. It will be the same with robotics and technology. He suggested that we need to rethink the structure of our institutions as one example of "rethinking" our future direction to accommodate robotics. Older buildings, compared to future hospitals and delivery systems, will begin to accommodate automation and robotics to fully take advantage of the ability to use technology just as we did with the automobile.

Booth related that it would be important to determine what tasks are appropriate to delegate or "give away" to technologies and robots. Roles will change as we make room for how robotics can support nurses in their daily work. As such, Booth stated that "nurses need to get out in front of this technology wave (robotics) and not sit passively." Booth said that it will be important to consider the question, "What should we not be doing in the future that a robot could do for us?" Further, he cautioned that we should also ask ourselves, "What should we never automate?"

Roles will change as we make room for how robotics can support nurses in their daily work. As such, Booth stated that "nurses need to get out in front of this technology wave (robotics) and not sit passively."

"What should we never automate?" Booth discussed his research and noted that most of his research addresses ethical considerations and issues. For example, privacy and security can be an issue if we don't know where the data goes with some of these cloud-based systems,

"What should we not be doing in the future that a robot could do for us?"

particularly with robots that can be purchased for home-based use. Challenges with technology and human characteristics also present ethical considerations.

According to Booth (2019) nursing theory does not fit when you consider robotics and machine learning. Robots can now talk to you and listen to you; they blink, smile, and are designed to make you like them. In some of the robots, there is real-time machine learning involved with many of the systems. But how do you agree or disagree with a robot?

Booth recommended we consider focusing efforts on using robots to support nursing on high-repetition, low-skill tasks. He cautioned us that the gain we get from offloading tasks is not subsumed, that rather than give time back to the nurse for nursing care, patient teaching, and patient interaction, we instead simply give the nurse more patients. Gains on efficiency could be misused. There must be policies that accompany the initiatives to automate to protect against this type of situation. Policy should evolve to accommodate the role of nurses to do bigger and better things.

Dr. Barbara Cherry's Findings with Robotics Research. We conducted an interview with Dr. Barbara Cherry on August 21, 2019 (Cherry, 2019). Dr. Barbara Cherry is a professor at Texas Tech University Health Sciences Center in Lubbock, Texas, and Chair of the Graduate Leadership Department in the School of Nursing. Cherry, a nursing researcher and robotics subject matter expert, was interviewed as part of the information gathering for this white paper. Cherry was part of a two-year (2015–2017) National Science Foundation (NSF)–funded grant aimed at examining the opportunities for the use of robots for care delivery in patients' homes and in long term care (LTC) facilities. She worked with robotic engineers from Mohan University in New Zealand to document the potential service delivery needs of patients in their homes that could be conducted by robots. This information was gathered via observing the caregivers as they cared for the patients.

The grant team used the social-technical systems model that involves people, information, and work in this case. The main themes that emerged were the following:

- Robots must be able to pick up a change in physical status or emotion.
- Webcams should be placed in the home for viewing.
- Robots must be able to engage in complex decision-making.
- Patients are more likely to be suspicious of a stranger caring for them than a robot.
- Barriers in the home are significant and include carpet, stairs, small spaces, and furniture.
- Instead of adding more devices to the home for comprehensive monitoring, add these to the robot, making this equipment part of what constitutes the robot equipment and services.

The grant team concluded that we could not replace care delivery, but we could augment care delivery.

In terms of the caregivers, they reported that their jobs differed each day based on the needs of their patients, and they questioned how robots would know the patient well enough to notice those changes. The grant team concluded that we could not replace care delivery, but we could augment care delivery. As with other such studies, return on investment (ROI) will be a challenge, but nursing needs to be prepared to address some of these issues where robots are caregivers in the home (Cherry, 2019).

Common themes in the interviews with Booth and Cherry were that the nursing profession needs to prepare for robotics impacting, augmenting, and supporting care delivery systems from acute care to the home environment. Both researchers indicated that nurses are needed to fully grasp the workflow and understand what tasks can be offset or augmented. The researchers' impressions of how robotics will impact nursing, did differ somewhat. Booth indicated he thought we needed to prepare to give away tasks, whereas Cherry felt that, instead, robots would augment what nurses do and could not replace nursing care delivery.

Most authors agree that robots do not present a replacement for the healthcare provider's role of "caring."

Nursing "Care" versus Technology

There is much discussion about the role of health care delivery robots compared to that of nurses. Most authors agree that robots do not present a replacement for the healthcare provider's role of "caring." Dr. Anees Fareed, the chief medical information officer of Al Jalila Children's Specialty Hospital in Dubai, United Arab Emirates, said it best:

> Robots play a great role in improving efficiency of the health care workforce by taking over tasks that are repetitive and monotonous but requiring constant attention to detail. Implementing robots into an organization's business model provides preciseness of completing these tasks, helps reduce the workload of health care workers and gives them more time to spend with patients and focus on other important activities. (Fareed, 2017, para. 2).

Others have been more specific but tend to align with the focus on caring being delivered by the nurse. Locsin and colleagues (2018) discussed and outlined "competency of caring in nursing" components as a means to address the issue of caring (Boykin & Schoenhofer, 2001). These components include five assumptions that structure the theory of the relationship between technology, caring, and nursing. These assumptions are summarized as follows:

1. Persons are caring by virtue of their humanness. In nursing, caring is the substantive focus of the discipline.
2. The ideal of wholeness is a perspective of unity. Persons are known as wholes in ways shaped by philosophical truths. As such, the nurse focuses on the person being nursed rather than focusing on fixing the person or completing the person's lack or missing "parts."
3. Knowing persons is a multidimensional process. The nurse and nursed engage in appreciating, celebrating, supporting, and affirming each other while allowing for mutual recognition as dynamic participants in their care.

4. Technologies of health and nursing are elements for caring. Through their practice, these nurses can know persons more fully as active contributors in their care, rather than only as objects of care.
5. Nursing as a discipline and a professional practice provides the essential opportunity for engagement in the scholarship of practice grounded in caring (Boykin & Schoenhofer, 2001; Locsin & Ito, 2018).

In addition to the consideration of nursing being grounded in caring, ethical issues with technology in general have surfaced.

In addition to the consideration of nursing being grounded in caring, ethical issues with technology in general have surfaced. For example, with the EHR-based clinical decision support (CDS) guiding actual clinical practice decisions, ethical decision-making occurs (McBride et al., 2018). With EHRs and the associated CDS alerts and guidelines displayed for nurses' use, ethical dilemmas are common, and nurses sometimes find themselves ill-equipped in managing them. The critical question remains, with the advent of intelligent machines and robotics, will the practice of nursing, while grounded in caring, continue to epitomize caring practice?

Nurses must be a patient advocate to ensure robot technology maintains patients' dignity, privacy, preferences, and safety and that it is used in an ethical manner with patient consent. Ethics should serve as a platform to help developers innovate technology in an end-user/patient respectful manner (Mahoney, 2019). Nurses across the spectrum of practice need to reflect and consider what is the essence of humanistic, caring nursing practice and how it needs to be safeguarded from loss during the implementation of robotics-based care delivery.

Patient Safety and Quality Metrics

The Institute for Healthcare Improvement (2019) recommends three types of measures with the implementation of quality improvement projects: outcomes, process, and balancing measures. As we consider the implementation of robotics to improve care delivery by nurses, these types of measures are important to define and implement. Outcomes measures for the use of robotics in nursing often relate to medication management, focused on the reduction of medication errors. Safety metrics may include measures that relate to improved outcomes for fall prevention (Kangasniemi et al., 2019). Process measures may include

Additional considerations for quality and safety are monitoring for unintended consequences.

such things as time to delivery supplies or reduced steps taken to retrieve and deliver supplies needed.

Additional considerations for quality and safety are monitoring for unintended consequences. These measures are often considered balancing measures to address the potential for adverse events, impact on staff, or patient satisfaction that may be either positive or negative. Adverse events in patient safety associated with health care service robots (although they have the potential for error) are not as significant as with other types of robotics such as surgical robotics that carry a higher risk for error to the patient (George et al., 2018).

There is evidence that robotics relating to surgeries have a long history of having the potential for injury. Surgery in and of itself has risk; therefore, robotics used carry that risk (Alemzadeh et al., 2016). This is different from the use of service robots to support nursing, which is more like other common industrial uses of robotics, but it is notable in terms of highlighting the need for safety precautions. These precautions are noted in the following section.

Safety precautions are frequently discussed in regard to the impact of robots in service and industrial settings. Smyth, of EngineerLive (2019), discussed common industrial robot malfunctions. Some of the notable incidents caused by robotic failures included a robot smashing and destroying things and others even causing deaths. While these issues are not associated with health care use, they are important to consider as we look to expand the use of robots in health care delivery. Some of the causes of robotic malfunctions include:

- **Human errors:** This could be because of the original programming or if an individual connects live input-output sensors to microprocessors. Another human error is performing a wrong activation of the teach pendant or the control panel.
- **Control panels:** These could be errors in the robot's software or electromagnetic and frequency interference. This leads to the failure of the robot. The malfunctions could also occur because of hydraulic, electrical, and pneumatic sub-controls that are associated with the robot system.

- **Mechanical failures:** If the operating programs do not account for a cumulative mechanical part failure, it could lead to an unexpected operation or faulty functioning.
- **Environmental resources:** Electromagnetic frequency interference leads to undesirable effects on the robotic functionality, and this leads to the potential for an injury or property damage.
- **Power system disruption:** These could result from hydraulic, electrical, and pneumatic power sources malfunctioning. This disrupts the electrical signals, which increases the risks of fire occurrence.
- **Wrong installation:** This starts from the design, equipment layout, and requirements of the robot system. If incorrectly done, it could result in the malfunctioning of the robot (Smyth, 2019, para. 2).

Most personal health information generated, shared, and utilized by robots in the traditional health care setting will be subject to HIPAA Privacy and Security Rules.

Policy Formation/ Nurse Practice Act / Roles of Nurses

One significant consideration with robotics is Health Insurance Portability and Accountability Act (HIPAA) privacy and security constraints due to robot-carried protected health information (PHI). Most personal health information generated, shared, and utilized by robots in the traditional health care setting will be subject to HIPAA Privacy and Security Rules. The HIPAA Privacy Rule "provides federal protections for individually identifiable health information held by covered entities and their business associates" on whom the rule places duties, which are enforced by the U.S. Department of Health and Human Services (HHS) Office of Civil Rights (OCR). Robotics uses we describe for home care, particularly coupled with telehealth, will constitute care coordination ability. Many of these home-based robots are not likely HIPAA compliant but should be (Simshaw et al., 2016).

Cost-effectiveness

Studies have indicated that robots working with nurses to deliver patient care tend to be cost-effective (Kangasniemi et al., 2019). In fact, the pilot sites associated with this white paper illustrated time savings associated with less nurse time spent walking and less waste of

The average savings secured by the implementation of robots in the industrial workplace is a robust 17.71% It is expected to grow beyond 21% by 2020.

supplies. Other results, such as a decrease in potential fall injuries due to better compliance with fall risk notifications, may offer more cost savings.

Modern industrial robots can help businesses unlock tremendous savings. Recent research suggests the average savings secured by the implementation of robots in the industrial workplace is a robust 17.71% (Robotics Online Marketing Team, 2019) . It is expected to grow beyond 21% by 2020. Key areas of savings include increased productivity, workplace safety, and high-level focus of employees. This observation in the industrial workplace has implications for health care supply chain management.

Increased Productivity. Productivity gains may be the number one area where robotics helps most manufacturers. Through effective design and implementation of robotic systems, it becomes possible to extend uptime and minimize downtime. Industrial sites that once ran on an 8- or 12-hour day can easily be extended to 24-hour operation through modest investments (Robotics Online Marketing Team, 2019) .

Greater Workplace Safety. The core concept of industrial robotics is to perform repetitive or dangerous tasks. In robotics' early history, "repetitive" was the operative word. Now, robots are mastering dangerous procedures as well. When robots are deployed properly, the workplace can be reengineered for fewer pinch points and other hazards to humans. That, in turn, leads to fewer injuries and reduces time away from work (Robotics Online Marketing Team, 2019).

High-Level Focus of Employees. The full potential of humans and robots can be realized when they work together. When robots are part of the workplace, companies get a chance to focus on a more professional, skilled, strategic workforce. Team members have the opportunity to spend more time on high-level tasks and innovation while spending less time on manual labor or passively supervising their equipment. That adds value for the employees and the enterprise at large (Robotics Online Marketing Team, 2019).

NEW POSSIBILITIES FOR ROBOTICS

Robotics Application to Nursing Practice

As the progress of robotics in health care evolves, the roles of nurse leaders and practicing nurses should be thoughtfully examined. The new possibilities for care delivery where service robots such as Moxi (Diligent Robotics Inc., 2019) work side-by-side with nursing provide great opportunities for improved outcomes, increased efficiencies, and reduced cost. Much of these outcomes were illustrated in the pilot sites outlined in this report. However, it will take nurses working in tandem with engineers and developers, as demonstrated in this case study of pilot sites, for optimum patient safety and quality outcomes to be achieved. The details for how the unit runs, the daily routines, and the uniqueness of the patient and family needs must be carefully integrated into the robotic activities.

It will take nurses working in tandem with engineers and developers, as demonstrated in this case study of pilot sites, for optimum patient safety and quality outcomes to be achieved.

The nature of what nurses integrate with robots should be carefully considered. It was suggested by Booth that the long-term impact of changes in nursing practice be considered as workflows are rearranged with robotics integration. We recommend that a combination of the state boards of nursing, the nursing practice associations, and representatives from nursing schools have a structure whereby they can work together to consider health care robotic industry developments and how they might impact nursing practice. This is like the approach taken when the EHRs were introduced into the health care system in 2010 and white papers, position statements, and standards of care followed in nursing organizations. As we consider how robotics will change or augment the way we support and deliver care, these types of structures, position statements, and standards of care may need to be developed.

Robotics and Leadership from Interviews with Thought Leaders

The subject matter experts in robotics in nursing indicated that significant strategic planning is warranted by the profession. Booth indicated that nursing must consider "who is to blame" when a robot makes an error in care delivery that harms a patient (Booth, 2019). Is it the nurse associated with the robot, the engineer who programmed the robot,

Strategies for implementing robots into nursing units need to consider patient safety, quality, efficiency, and ROI.

the manufacturer of the robot, or someone else? Nursing should also consider the ethics of how emotions and factors such as respect for the patient will be carried out by robots. Robotic engineers have indicated that meta-analytic emotional components can be created and used in humanoid robots; however, nursing did not take part in the creation of these components, so one would question the authenticity.

Cherry focused on the physical assessment and physical care delivery by robots and suggested that peripheral devices for patient physical assessment be included as part of the robot physical structure (Cherry, 2019). She emphasized that robots in the home should take up little space and as such, should include the monitor to watch television, the telephone for communicating, and the calendar with reminder notices. Nursing leaders must become familiar with concepts such as emotion and special efficiency for robots to better support future robotics integration in nursing practice.

Executive leadership and directors of nursing at the pilot sites also identified important considerations for the adoption and implementation of robotics into nursing. Strategies for implementing robots into nursing units need to consider patient safety, quality, efficiency, and ROI.

LIMITATIONS

Case Study Pilot Sites Status

This project was designed as a case study review of three pilot site experiences with service robots. and not as a research study. It is important to note that each site conducted the pilot differently: one as an official IRB-protected research study, another as a quality improvement project with plan-do-study-act cycles, and another as an innovative technology implementation project. This varied approach has limitations in terms of generalizability. Additional limitations include the fact that each of the pilot sites was conducting the study for the first time. As such, the interface to the hospital's EHR system was not in place. Programming the computer code for Moxi and the needed service tasks required much time and effort as both the unit nurses and the Moxi engineers were needed when this was conducted for the first time.

Single Source for Service Robot

The fact that Moxi was the single source for the service robot being piloted is also a noted limitation. Although this provided some consistency in methods, the question of whether a different robot would or would not yield similar results could not be evaluated.

Exploration versus Implementation

This pilot study explored the use of service robots to support nursing care delivery. This contrasts with full robotics implementation and associated implementation guidelines. As such, details such as storage, cleanliness, failure management, etc., although needed, are beyond the scope of this paper.

We found the charge nurses and staff to be integrally involved in advising the daily operations of Moxi.

FUTURE CONSIDERATIONS FOR EDUCATION AND PRACTICE

Role and Education of Clinical Staff

The role and associated education of clinical staff involved in robotics integration into the work of nursing care delivery cannot be underestimated. For example, in this case study, we found the charge nurses and staff to be integrally involved in advising the daily operations of Moxi. They were also needed to maximize the technical interface between the EHR and Moxi's robotic activities. In this case study, engineers were present to write the code for the interface-type programs, but they did so guided by the clinical expertise of the staff nurses, the charge nurses, and the unit clerks. Additionally, nursing informatics specialists were consulted to support the EHR interface development. It is important that all areas of the team be educated and prepared to support adoption, implementation, and evaluation of these new technologies.

Adoption, Implementation, and Evaluation

Workflow Redesign. When adopting new technologies, it is important to consider workflow factors for the nursing units. The partnership between the vendor and the pilot sites did considerable work to map workflow relevant to the use tested at each site and to make sure that the robot addressed specific requirements for the institutions. Important considerations were facility layout, how the robot will maneuver through the facility, and the actual clinical workflow for that

Nursing informatics professionals are well prepared with competencies to support the adoption, implementation, and evaluation strategies for incorporating robotics into nursing practices.

institution to accomplish the tasks identified. As with our large-scale implementations of EHRs, robots and other new and advanced technologies will need to adopt best practices for determining current state workflows of the tasks and develop future state workflows of the tasks to be supported by robots. As noted earlier in this document, the Agency for Healthcare Research and Quality (AHRQ) has developed toolkits to support organizations in the adoption, implementation, and evaluation of new technologies. The additional time afforded by robotics could help address RN burnout and bring more joy back to nurses' patient care experience.

Evaluation Strategies. Evaluation strategies are also critical to how the organization will determine success. It is recommended that outcome, process, and balancing measures be identified prior to implementation using many of the best practice approaches for improving quality outlined by the Institute for Healthcare Improvement (2019).

Nursing Informatics Involvement. Nursing informatics professionals are well prepared with competencies to support the adoption, implementation, and evaluation strategies for incorporating robotics into nursing practices. ANA Scope and Standards of Practice defines nursing informatics (NI) as the specialty that integrates nursing science with multiple information and analytic sciences to identify, define, manage, and communicate data, information, knowledge, and wisdom in nursing practice (American Nurses Association, 2015). The standards also specifically note the importance of the NI specialty with robotics support, indicating that robotics has the potential to revolutionize health care (American Nurses Association, 2015, p. 57).

Research

Repetitive Task Management. Subject matter experts in the field of robotics indicated to us that nursing should be cautious and deliberate in what we "give away to robotics" and/or how robotics is to augment nursing care delivery. In the case of repetitive, task-oriented and automated robotic services delivery, we must consider that errors may indeed occur and be prepared for how to manage those events (for example, water may be delivered to a patient who is NPO, or instructed

nothing by mouth, for surgery). Just because the task is repetitive does not mean that there is potential for error or risk. Research and cautious consideration for workflow redesign will help guide these considerations.

Emotional Ambiguity. In the case of emotional-care-type robots, a great deal is assumed about their impact on the patient. Incorporating the ambiguity of human nature and human emotions is still a very young part of robotics care delivery. Sophisticated algorithms have been developed to manage robotics' decision making. However, these seem to lack some nursing input, and greater rigor of research is needed to measure true outcomes.

Like the nursing practice changes that were experienced through the HITECH Act's implementation of EHRs beginning in 2010, robotics has the potential to impact nursing care decision-making practice (U.S. Department of Health and Human Services, 2012). The integration of service robots such as Moxi with nursing care delivery appears to offer clear and useful improvements in patient care delivery. However, other robots that involve emotional support such as "Buddy" and "PARO" robots (see Appendix A), as well as some robots that interact directly with patients, are entering the arena where the ambiguity of decisions and associated statements are complex. These types of robotics seem to have a role in patient care delivery, but they should be monitored closely by nurses and other applicable health care team professionals with consideration for the impact of ambiguous robotic-patient interaction.

Nurses, nurse leaders, and nurse informaticists must own the role of patient safety protector in the evolution of technology integration into patient care delivery and practice.

Ethics and Patient Advocacy

Mahoney (2019) highlights that technology in itself is not bad or good; the human developers or users are the ones that are responsible for its actions. Nurses, nurse leaders, and nurse informaticists must own the role of patient safety protector in the evolution of technology integration into patient care delivery and practice. Schools must be prepared to teach this role to support this evolutionary process and examine ethical considerations for nursing practice. Robotic usage can be integrated into current course cases as a tool to debate the social, professional, practice, and ethical usage implications.

Delegation decisions are particularly relevant to robotics as the profession considers new models of delegation to include robotics- and AI-based delegation decisions.

Policy

Institutional Policy Implication. There are policy implications related to the need to standardize maintenance of supplies and to prioritize those items that are high repetition and typically small, such as gauze, bandages, and IV flushes. Some of these items present policy implications because the policy at one institution indicated that items had to have noted expiration dates. Small items such as Band-Aids often have expiration dates on the box. Therefore, policy needs to determine how to address supply management and monitoring of expiration dates. Another institutional policy issue relates to decisions about whether to allow Moxi into the patient's room and under what considerations. These issues primarily related to infection control.

Public Policy Implications: State and National. Robotics and other types of innovative technologies have significant policy implications for the nursing profession. According to the 2019 Environmental Scan by the National Council of State Boards of Nursing, nurse educators must anticipate disruptive technologies, such as robotics, artificial intelligence, and other computer technology advances. The report indicated nursing education must prepare for a "seismic shift" driven by new and emerging technologies. State boards of nursing, as well as federal oversight, must plan for these types of disruptive technologies to change the way professional nurses are prepared to practice in the digital age of health care (National Council of State Boards of Nursing, 2019).

Further, the American Academy of Nurses in its 2019–2020 policy priorities included a focus on promoting innovation and sustainability through advancing policies that adopt modernizations, treatments, and new models of care that include technological advances (American Academy of Nursing, 2019). As technologies (such as robotics) support new models of care, with implications for the professions of nursing and nurse delegation, it is critical that the voice of nurses be represented in policy making to inform safe and effective care.

Delegation decisions are particularly relevant to robotics as the profession considers new models of delegation to include robotics- and AI-based delegation decisions (van Wynsberghe, 2013). Currently, we have a delegation policy for human to human (generally a higher scope

practitioner to a lower scope practitioner). We must now consider how delegation will look when it is human to nonhuman "thing" that can think, do, and act (e.g., advanced-level decision support AI technology for some select conditions). As we progress into the future, this delegation policy between human to nonhuman (and vice versa, as sometimes a nonhuman will delegate a human to do something) is going to be extremely important to manage safely, legally, and ethically.

Other critical questions to consider are: "What tasks can be delegated to robotics related to nursing care?" and "Who accepts the responsibility for the delegated task?" In 2016, the National Council of State Boards of Nursing released national guidelines for nursing delegation. They addressed responsibilities based on role, employer, licensed nurse, and delegate (National Council of State Boards of Nursing, 2019). The responsibilities of the delegate are noted as a) accept delegation if competent to undertake the task, b) maintain competence level for the delegated task, and c) remain accountable for the delegated task. In the scenario of a humanoid robot, the robot is the delegate. New and emerging technologies have significant implications for nursing leadership, employers, and the profession and they must consider new guidelines such as a nursing delegation model and criteria for delegation decisions.

Implementation of robotics and associated integration of robots with patient care delivery must include collaboration with organizations such as the ANA.

Collaboration with Key Organizations. Implementation of robotics and associated integration of robots with patient care delivery must include collaboration with organizations such as the ANA. Specialty organizations such as the American Nursing Informatics Association (ANIA) and the American Organization of Nurse Leaders (AONL) must also be a part of preparing for robotics in nursing. Seeking the expertise of members on the American Academy of Nursing (AAN) expert panel on information technology should be considered for overall policy guidance.

Economics

Time Back to the Nurse. The analysis of economics such as the returns on investment made with the application of robotics is in its early stages. The value equation of what is gained by the use of robotics for patient care delivery is at the heart of the discussion. We believe the

Additional time also improves the safety on the unit; instead of the nurse leaving the unit to run errands, Moxi does so.

credit of additional time provided "back to the nurse to be with the patient" must be protected. It was clear that Moxi provided services that the nurse no longer was required to provide, and as a result, the nurse has additional time to spend with the patient. The additional time was used for emotional support and for education in preparation for discharge. According to Booth (2019), these types of time saving activities must be protected by leadership and not misused to decrease the numbers or hours of time that a nurse is assigned to a given unit or to increase the number of patients the nurse cares for on the unit.

Time for Safety Improvement. Additional time also improves the safety on the unit; instead of the nurse leaving the unit to run errands, Moxi does so. This leaves the nurse and other skilled personnel on the unit with eyes on patients, thereby enhancing safety and preventing harmful events such as accidental falls.

The robotics health care industry appears to be supported by sound financial support reflected in research and development. Part of the industry-based financial support should be allocated for support of nursing involvement in the development process. Nursing leadership and practicing nurses in these pilot studies played an integral role in the development of Moxi, so further support of their education in robotics and in their investment of time to the project should be considered.

CONCLUSION

The evolution of robotics in nursing has progressed from physiological monitoring, IV pumps, and barcode medication management (Kangasniemi et al., 2019) to the next generation of mobile robots with tactile arms. Kangasniemi's systematic review of 25 studies examined robots involved in medication management or physiological monitoring (except for only three or four). As such, this manuscript has focused on the next generation of robots, which are mobile, have multilinked manipulation (arms), and have varying degrees of AI to serve as service robots. This entry into the health care industry is the latest in the evolution of robots to support health care workers such as nurses (Kangasniemi et al., 2019).

Nurses have always had to learn how to use apply technologies and equipment in their clinical practices, for example, hemodialysis machines, ventilators, etc. Robots have been under development in health care for over two decades, and many believe that robots are just now approaching practical utilities in care services. In fact, robots may require another decade of development before meaningful use, true reliability and robustness are present. In terms of the impact on nurses and nursing care delivery, it is likely that robots will not produce a seismic imminent change. Subsequently, it is suggested that in preparation for change, educators can begin to integrate robotics into current courses. Further, educators can use robotics content as a tool to debate the social, professional, practical, and ethical usage implications of robots in nursing practice (Mahoney, 2019; Mahoney et al., 2007).

Educators can use robotics content as a tool to debate the social, professional, practical, and ethical usage implications of robots in nursing practice.

Regardless of the speed with which this transition will occur, robotics associated with patient care will very likely transform and revolutionize the way we support, augment, and deliver care. The Moxi team, the three health care organizations, and nursing researchers involved in this case study are thought leaders, early adopters, and innovators helping to shape these health care delivery opportunities. Their accomplishments and subsequent documentation here have paved the way for all of us to consider how robots will help shape care in the future. The leadership at these Magnet-based organizations, with their forward-thinking approaches, have provided examples for improved patient safety such as fall risk management, improved staff productivity in terms of fatigue or steps walked, and improved staff satisfaction by increasing the time nurses spend with their patients.

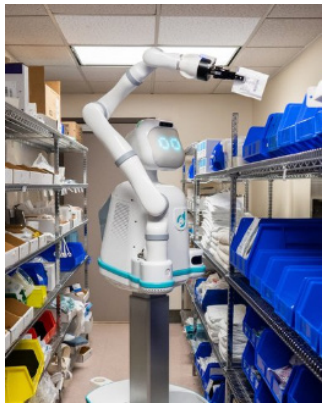
In order to expand on this success, nursing researchers, educators, and leaders must work with professional nursing organizations for a structured process to develop new policies, standards, and recommended guidelines to help shape these innovations in nursing care. This paper reviewed the current state of the science of robotics used to support nursing, particularly service robots, and explored the experiences of three pilot sites to examine themes across these institutions. Subject matter experts were interviewed, and those interviews were summarized. Finally, recommendations were made for how organizations can prepare to embrace the inevitability of robots supporting nursing care

Ultimately, nurses want to nurse their patients, not a technology.

delivery and how the profession can capitalize on the future use of robotics in nursing care. This white paper begins to lay a foundation for these discussions and further national recommendations to support the adoption and implementation of robotics to support nursing care delivery.

One can now envision a future where robots can support nursing in an integrative fashion and work alongside nursing. For example, discharge planning is frequently a task for a professional RN. Could robots partner with nurses to reduce the discharge planning time? While the nurse is busy with other patients, a pre-visit by a robot could be scheduled. The robot could help patients or family pack by audio reminding them to check the bathroom, drawers, and closet. The robot could bring the discharge checklist to the patient and family ahead of time for review, prompting questions about new medications, routines, treatments, and a follow-up visit appointment. The robot could guide the preparation for carrying out flowers and bags. The nurse could then arrive and focus on helping the patient understand his or her medications and treatments, reviewing follow-up care expectations and information family members need to know, and offering resources to heal and prevent illness reoccurrence (Mahoney, 2020). Robots are not to replace nurses but to augment and empower the nursing profession.

Appendix A
Select Robots from the Robotics Marketplace

Product	Company	Website	Category	How Used	Image
Buddy	Blue Frog Robotic (Paris, France)	https://buddytherobot.com/en/buddy-the-emotional-robot/	Emotional companion robot	Buddy has a range of emotions that he will express naturally throughout the day, based on his interactions with family members. He will be happy to give you a warm welcome when you come home or sometimes be grumpy if you have not paid attention to him, or just because that morning, he is not in a good mood. Buddy won the CES Innovations Award in 2018.	
Moxi	Diligent Robotic, Inc. (Austin, Texas, USA)	https://diligentrobots.com/moxi	Robot assistant, service robot	Moxi is a socially intelligent health care service robot that helps nurses and clinical staff as a member of the team with their nonpatient-facing logistical tasks. Moxi helps gathering and delivering supplies for new patient admissions, delivering lab samples, and carrying out heavy linen bags as part of cleaning rooms. As a result, nurses have more time for patient care. Moxi is being trialed in several US hospitals. It helps hospitals cut costs, improve efficiencies, increase employee satisfaction and enhance patient care.	 

Product	Company	Website	Category	How Used	Image
Moxi (continued)					
My Spoon	SECOM Co., Ltd (Tokyo, Japan)	https://www.secom.co.jp/english/myspoon/	Care robot	My Spoon offers meal assistance, allowing eating with only minimal help from caregivers.	 
PARO Robot	2014 PARO Robots U.S., Inc AIST (Nanto, Japan)	http://www.parorobots.com/	Therapeutic robot	PARO offers benefits of animal therapy to be administered to patients in environments such as hospitals and extended care facilities where live animals present treatment or logistical difficulties.	

Product	Company	Website	Category	How Used	Image
Pepper	SoftBank Robotics Holding Corporation (Tokyo, Japan)	https://www.softbank-robotics.com/	Humanoid with an emotion engine	Pepper is the world's first social humanoid robot able to recognize faces and basic human emotions. Pepper was optimized for human interaction and is able to engage with people through conversation and his touch screen. Standing 120 cm tall, Pepper has no trouble in perceiving his environment and entering into a conversation when he sees a person. The touch screen on his chest displays content to highlight messages and support speech. His curvy design ensures danger-free use and a high level of acceptance by users. Pepper is available today for businesses and schools. Over 2,000 companies around the world have adopted Pepper as an assistant to welcome, inform, and guide visitors in an innovative way.	 
RIBA (Robot for Interactive Body Assistance), also known as "Robear."	Intelligent Sensor Information Processing Lab (ISIP) (Nagoya, Japan)	Formerly, RIKEN-TRI Collaboration Center for Human-Interactive Robot Research (RTC), dissolved in March, 2015: httpa// rtc.nagoya.riken.jp/ index-e.html Currently, Intelligent Sensor Information Processing Lab: http://www2.meijo-u.ac.jp/~mukai/index-e.html	Care robot	ROBEAR has tactile sensors and serves as a tactile interface nursing care robot. It helps patients into and out of wheelchairs and beds with its strong, actuated arms and tactile sensors. It provides autonomous lifting.	

Appendix B
Summary of Case Study by Pilot Site

Pilot Site Characteristic	Presbyterian Hospital Dallas	University of Texas Medical Branch	Houston Methodist Hospital
Background	The first of the three sites to go live. An innovative focused neurological unit was selected for the pilot.	The second of the three sites to go live. The robotics project at UTMB was conducted in the John Sealy Hospital, which sits within a major UT Health Sciences Center in Galveston, Texas, and is an academic teaching center. The robotics pilot took place on a medical-surgical unit.	The third of the three sites to go live. The robotics project at HMH was conducted in a large metropolitan hospital in the heart of the Houston Medical Center. The robotics pilot took place on a medicine-telemetry unit.
Literature search conducted?	1. No		
IRB or QIRB?	2. No	1. Yes	1. Yes
Demographics	3. Demographics	2. Yes	2. Yes
a.. Name	a. Texas Health Presbyterian Hospital in Dallas, TX	3. Demographics a. University of Texas Medical Branch in Galveston, TX	3. Demographics a. Houston Methodist Hospital, Houston, TX
	b. 898 acute care beds		
b .Beds	c. 821	b. 561 acute care beds	b. 1,403 acute care beds
c. Average daily patient census	d. No	c. 500	c. 769
d. Academic institution	e. Yes	d. Yes	d. Yes
e. Magnet status	g.1. Hamon 4 N Neuro	e. Yes	e. Yes
g.1. Nursing unit name	g.2. Neurology	g.1. Jennie Sealy 9C	g.1. Not provided
g.2. Specialty	g.3. 21	g.2. Medical-Surgical	g.2. Not provided
g.3. Beds	g.4. 40 employees	g.3. 16	g.3. 20, average 16
g.4. Employee count		g.4. 43 employees	g.4. 35 full-time equivalents full-time equivalents
Other Background Information			This institution coupled the pilot project supporting nursing units with supply and linen delivery with an approach to improving quality and safety with a fall risk improvement strategy. The pilot study assumption at this institution was that Moxi would improve patient outcomes by assisting in fall prevention audits, increase staff engagement satisfaction, and increase patient satisfaction. This institution conducted the project as a beta test on the pilot assumptions as a proof of concept. The project included an interdisciplinary team with IT, Nursing, Education Department, Infection Control Department, Quality Unit, and hospital leadership. Input from physicians, visitors, and patients/families were also included.

Pilot Site Characteristic	Presbyterian Hospital Dallas	University of Texas Medical Branch	Houston Methodist Hospital
Case Study (Pilot Site)	Case Study (Pilot Site)	Case Study (Pilot Site)	Case Study (Pilot Site)
A. Opportunity Statement	Moxi will give time back to the nurse to spend time with the patient for the purposes of education, discharge planning, and family interaction.	A. Learn about and recognize what it's like to work with an autonomous robot to provide patient care. With this information, we aimed to assess the feasibility and improve resources and technology to support health care professionals in caring for patients.	A. Per the Diligent Robotics report, Moxi completed over 1150 tasks over the course of the 1-month trial. Moxi's tasks included trips to/from the supply/linen and Central supply department rooms. Moxi completing tasks may have saved the nurses and patient care assistance about 3.5 hours per day. Moxi's linen deliveries had a positive impact on daily linen changes, and Moxi helped assist with fall prevention compliance audits, had the potential to impact service and quality.
B. Study Design Objectives	B. Not applicable	B. - Learn how health care staff feel about working with an autonomous robot - Identify what went well and what did not - Determine the feasibility of working with this type of technology Staff were asked to complete a questionnaire and talk one-on-one with staff about their experience. The questionnaire, the System Usability Scale (SUS), is a simple questionnaire that measures how individuals perceive working with computer systems. The SUS tool was modified to assess an individual's perceptions of working with autonomous robots and renamed the Robot Usability Scale (RUS) for this study.	B. Not provided
C. Study Population	C. Clinical staff such as nurses	C. Clinical staff such as nurses	C. Clinical staff such as nurses

Pilot Site Characteristic	Presbyterian Hospital Dallas	University of Texas Medical Branch	Houston Methodist Hospital
D. Study Methodology 1. Database Holding Data 2. Data Collection Form	D. Observation	D. Observation	D. Observation
E. Data Analysis 1. Study Question(s) 2. Statistical Methods	E. Not applicable	E. Not provided	E. Not provided
F. Summary of Findings	F. Moxi was found to provide about 5 minutes per nurse per patient	F. Not provided	F. Findings for their quality improvement study utilized statistical analyses supported by Microsoft Excel, graphs, and run charts to determine findings.
G. Barriers	G. Not applicable	G. Not provided	G. Not provided
H. Robotic Impact on Nursing Care Delivery	H. Not applicable	H. Not provided	H. Not provided

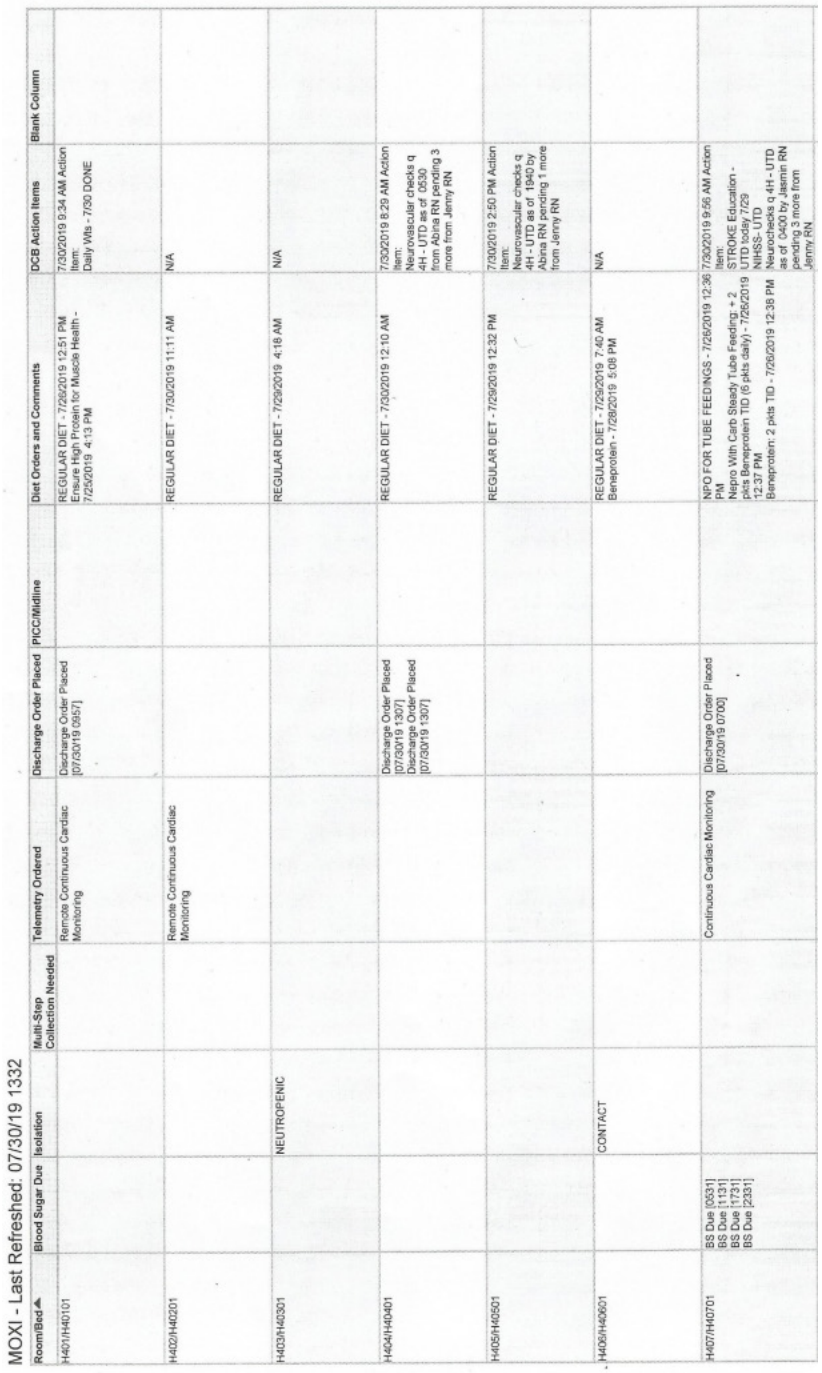
Appendix C
Charge Nurse Shift Report by Major Activity

Charge Nurse Shift Report Sheet

Charge Nurse	Ana Lopez (11/16/2018)
Current Census (0700)	23
Current Number of RNs	6
Current Number of PCTs/US	3/1
Anticipated Discharges	417,425,410,405
2x10's	NA
Pts Going for Procedure/Type	421- TEE
Call-Ins	NA
Names of Staff Floated Out/Where	NA
Names of Staff Floated In	Charisse Archie PCT (J3W)
Staff Delays	NA
Staff Cancellations	NA
Safety Issues/Incidents	NA
Midnight Census	23
Observation Patients	408,409,412,414,415,416
# Of Patients with Foley (and room #)	423
# Of Patients with Central Lines (and room #)	418 Dialysis
Stroke Patients (room #)	420,421,410
# Of Patients on Restraints (and room #)	422
Telemetry Patients (room #)	402,409,410,412,414,418,419,420
Core Measure Patients (room #)	420,407,423,424,425,409,401
High Risk Fall Patients (room #)	418,412,408
Blood Sugars (room #)	412,414,417,419,421,422,423
Total Care Patients (room #)	422,409,421,418,406
Daily Weights (room #)	401,404,409,412,414,418,420,422
Urine Specimen Orders (room #)	409
Stool Specimen Orders (room #)	NA
Sputum Specimen Orders (room #)	NA
RED ROOMS	NA
Isolation	409
Notes EEG Heparin drip Tube Feed Dialysis	. 415 406 418,421

Please report to the Moxi team any additional labs/tubes needed outside of our standard Purple or Green tops! They will be happy to have them available for you!

Appendix D
Charge Nurse Shift Report by Patient



MOXI - Last Refreshed: 07/30/19 1332

Room/Bed	Blood Sugar Due	Isolation	Multi-Step Collection Needed	Telemetry Ordered	Discharge Order Placed	PICC/Midline	Diet Orders and Comments	DCB Action Items	Blank Column
H401/H40101				Remote Continuous Cardiac Monitoring	Discharge Order Placed [07/30/19 0957]		REGULAR DIET - 7/26/2019 12:51 PM Ensure High Protein for Muscle Health - 7/29/2019 4:13 PM	7/30/2019 9:34 AM Action Item: Daily Wts - 7/30 DONE	
H402/H40201				Remote Continuous Cardiac Monitoring			REGULAR DIET - 7/30/2019 11:11 AM	N/A	
H403/H40301		NEUTROPENIC					REGULAR DIET - 7/29/2019 4:16 AM	N/A	
H404/H40401					Discharge Order Placed [07/30/19 1307] Discharge Order Placed [07/30/19 1307]		REGULAR DIET - 7/30/2019 12:10 AM	7/30/2019 8:29 AM Action Item: Neurovascular checks q 4H - UTD as of 0530 from Abina RN pending 3 more from Jenny RN	
H405/H40501							REGULAR DIET - 7/29/2019 12:32 PM	7/30/2019 2:50 PM Action Item: Neurovascular checks q 4H - UTD as of 1940 by Abina RN pending 1 more from Jenny RN	
H406/H40601		CONTACT					REGULAR DIET - 7/29/2019 7:40 AM Beneprotein - 7/28/2019 5:08 PM	N/A	
H407/H40701	BS Due [0531] BS Due [1131] BS Due [1731] BS Due [2331]			Continuous Cardiac Monitoring	Discharge Order Placed [07/30/19 0700]		NPO FOR TUBE FEEDINGS - 7/26/2019 12:36 PM Nepro With Carb Steady Tube Feedings + 2 packs Beneprotein TID (6 pkts daily) - 7/26/2019 12:37 PM Beneprotein: 2 pkts TID - 7/26/2019 12:38 PM	7/30/2019 9:56 AM Action Item: STROKE Education - UTD today 7/29 NIHSS- UTD Neurochecks q 4H - UTD as of 0400 by Jasmin RN pending 3 more from Jenny RN	

Appendix E
Proposed Meeting Agenda for Site Visit by Researcher

Proposed Meeting for Site Visit Agenda

1:00 PM 1:15 -3:00 PM	Meet with contact person A. **Introduction**s overview of visit with leadership • explain reason ANA is interested in documenting this experience for future nursing practice. • brief summary of the use of robotics in their institution: B. **Meet with staff members** involved in the project and the impact of Moxi on nursing care, suggestions on who might be included: • Researcher/Project Lead, • Clinical leadership, • Nursing Administrative leadership, • Nursing Informaticists, • nurses from the unit that experienced Moxi, and/or • Educators (and others as applicable) C. **Questions** to be discussed with those involved with Moxi - direct and indirect: 1. Describe how you used Moxi 2. What worked well for you? 3. What did not work so well for you? 4. How did Moxi impacted the nursing care on the unit? **D. Optional**
3:00 -3:30 PM	• If applicable, clinical walk through/observational assessment • Visit the Unit and speak to nursing and support staff on use of Moxi [see questions in section C above]
3:30-4:30 PM	• Optional: Discuss Case Study template and address questions and approach to completion (optional) • Schedule Zoom meeting to do this • Closing meeting with leadership to conclude and share brief summary of accomplishment (optional)

Note: Agenda item "D" was included as a workflow mapping activity for documenting robotics use by nurses. However, this activity was optional based on preference of the site.

Appendix F
Theme Categories for Staff Comments

Positive -Neutral/ Neg	Themes Category	Themes
Neutral/Neg	Comparison to Nursing	"I can do it better and faster."
Neutral/Neg	Emotional Response to Pilot/Moxi	Feeling the impact when Moxi was gone
Neutral/Neg	Importance/Need for Workflow Knowledge	Knowledge of workflow
Neutral/Neg	Neutral-Negative Impact/Performance	Not useful
Neutral/Neg	Patient/Family Perspective Negative	Emotional responses of patients and family
Neutral/Neg	Physical Space Management	Mobility of Moxi
Neutral/Neg	Physical Space Management	Physical space of the site/blueprint
Neutral/Neg	Pilot-Based Potential for Future	EHRs interface implications
Neutral/Neg	Pilot-Based Potential for Future	Lack of information
Neutral/Neg	Pilot-Based Potential for Future	Limitations policy
Neutral/Neg	Pilot-Based Potential for Future	Limitations capability
Neutral/Neg	Pilot-Based Potential for Future	Potential for impact
Neutral/Neg	Pilot-Based Potential for Future	Secondary learnings as the pilot progressed impacted success
Neutral/Neg	Safety Impact	Infection control implications
Neutral/Neg	Safety impact	Patient/visitor supply access safety
Neutral/Neg	Staff Perspective Negative	Suspicious or fearful of purpose of robot
Neutral/Neg	Supply Impact	Waste or increased utilization of supplies with Moxi
Positive	Basic Patient Needs	Water availability
Positive	Basic Patient Needs	Water availability
Positive	Emotional Response to Pilot/Moxi	Fun to have around
Positive	Emotional Response to Pilot/Moxi	Morale lifting
Positive	Newly Found Extra Time	Use of extra time as result of service offsetting tasks
Positive	Patient/Family Perspective Positive	Emotional responses of patients and family
Positive	Patient/Family Perspective Positive	Patients loved it
Positive	Positive Impact/Performance	Managing admissions
Positive	Positive Impact/Performance	Useful
Positive	Positive Impact/Performance	Efficiency patient safety
Positive	Positive Impact/Performance	Efficiency supplies
Positive	Positive Impact/Performance	Energy saving
Positive	Positive Impact/Performance	Improved workflow
Positive	Positive Impact/Performance	Walking fewer steps
Positive	Public Relations Impact	Positive image of the hospital or unit to have a robot
Positive	Supply Impact	Waste or increased Utilization of supplies with Moxi

Comments Supporting Themes from Interviews
I could do it faster, but it is better for Moxi to do it so I can do something else more useful.
We missed Moxi…
Charge nurses had a major role in directing the engineers for Moxi-programming for a given shift. They created a form for gathering and reporting the tasks and to what patient for Moxi each shift.
…didn't do any care, just grabbed stuff.
Patients suspicious of robot's eyes recording them.
There were sensor requirements on the floor and outside the room to tell Moxi where to go.
Day shift is more chaotic, and Moxi didn't have enough space to maneuver on-demand. We had to wait until 11a.m. for anything to happen.
It would help if Moxi knew the orders and details about the patient.
We get an order that a new admission is coming, but we don't know the size of the patient and details.
Small units with expiration dates on the box, not on the individual packages, couldn't be placed in drawer outside of the room per policy, so couldn't put some supplies in the drawers outside of the rooms.
She couldn't take vitals, assessments, or chart for us. Eventually yes, maybe robots can help nurses if they can take vitals, but we are not there yet.
I could see Moxi helping with, say, a deteriorating patient, and Moxi gets the crash cart or pulls up the order set in EPIC.
Examples: flags on the bins needed to be larger.
We worked with infection control to make sure there were no issues.
No needles or medications were allowed to be in the bins because they were not locked.
We had to keep reminding ourselves and others that Moxi was not replacing nurses or people.
My linen expenses increased when Moxi was here (Because of not doing linen changes before).
No one was without water when Moxi was here.
Medications were easier to give because water was always available.
I thought it was so much fun. It gives me so much joy; it is why I went into leadership. Technology is there, but we have a way to go. This project sheds light on how nurses can be innovative.
I loved it, did not have a problem with it. It meowed at me with two hearts.
When Moxi gives time back to the nurse, I most commonly used it for education, discharge planning, and family interaction.
Seemed to bring joy to the patients and family.
Good for entertainment and patients loved seeing it!
The rooms were always ready as long as Moxi knew of the discharge.
We struggle with stock, Moxi would keep things stocked for us.
Fall risk supplies were distributed to given patients as soon as their fall risk status was determined/ordered. Moxi kept up with this better than own workflows.
IV flushes handy outside the room really helped a lot.
Saved my energy.
Always continually needing supplies, having stuff in drawers by the room improved the workflow.
I walked less steps.
The hospital had an image of being innovative because of Moxi.
My linen expenses decreased when Moxi was here. (Moxi standard was to leave linen at the door, not in the room.)

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