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Addressing Interprofessional Competence in Interpretation of Electronic Fetal Monitor Tracings

Susan H. Hébert
University of Tennessee, College of Nursing, sfanche2@utk.edu

To the Graduate Council:

I am submitting herewith a dissertation written by Susan H. Hébert entitled "Addressing Interprofessional Competence in Interpretation of Electronic Fetal Monitor Tracings." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Nursing.

Joel G. Anderson, Major Professor

We have read this dissertation and recommend its acceptance:

Tami H. Wyatt, Mary C. "Cathy" Hammon, Suzan E. Kardong-Edgren

Accepted for the Council:

Dixie L. Thompson

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

Addressing Interprofessional Competence in

Interpretation of Electronic Fetal Monitor Tracings

A Dissertation Presented for the
Doctor in Philosophy
Degree
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Susan H. Hébert
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DEDICATION

This dissertation is dedicated to infants born with adverse irreversible outcomes resulting from unexpected events during the intrapartum period.

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ABSTRACT

Interpretation of electronic fetal monitor (EFM) tracings is a critical clinical practice skill nurses and physicians perform during the intrapartum stage of pregnancy. However, inaccurate interpretation can potentially jeopardize the well-being of the neonate by delaying preventative care interventions to promote the well-being of the unborn child. This project was initiated by completing a scoping review of the literature on the methods for training and evaluating competence in interpretation of EFM tracings, which revealed current EFM training and evaluation methods are lacking. A concept analysis defined nurse competence in diagnostic health care technologies including identification of surrogate terms, related concepts, attributes, antecedents, and consequences. Building on findings from the concept analysis and literature review, the dissertation study evaluated the feasibility and effectiveness of a Simulation-Based Mastery Learning (SBML) with deliberate practice (DP) intervention on clinical interprofessional team members' competence to interpret EFM tracings and self-efficacy compared with clinical experience alone. In addition, it determined how participants' characteristics are associated with baseline EFM interpretation scores. The study used a randomized longitudinal design with participants recruited from a convenience sample of interprofessional health care team members from a large research hospital in the southeastern United States. Randomization procedures placed recruited participants into either an intervention or clinical experience alone control group, with competence evaluations for both groups occurring at baseline, immediately post-intervention, and three months post-intervention. Results include evaluation data for 23 participants completing three outcome measures. Medium effect associations were present between baseline competence scores and level of education ($r=.36$) and EFM training ($r=.33$). Correlations of scores with clinical experience ($r=-.20$) and obstetric experience ($r=-.16$) showed a moderate inverse relationship. Univariate comparisons between groups across time showed significant results immediately post-intervention ($p=.006$), but not at the three-month follow up. Between group comparisons of accuracy in determining EFM criteria showed significant improvement in correctness of interpretations evaluating marked FHR variability ($p=.016$; $p=.029$; $p=.024$) and a Category III tracing ($p=.002$), and comparisons across the three evaluations were significant when evaluating FHR moderate variability ($p=.029$; $p=.044$), FHR minimal variability ($p=.004$), FHR marked variability ($p=.007$), FHR prolonged deceleration ($p=.004$), and three Category II tracings ($p=.043$; $p=.043$; $p=.041$), and one Category III tracing ($p=.047$). The intervention group scored higher percentages of correct responses to interpretation of tracings for all criteria questions showing significance in both between group and time comparisons. Regardless of study limitations, the results provide critical insight into the feasibility of using a SBML with DP intervention as an approach to promote improved accuracies and consistencies in interpretation of EFM tracings.

Keywords: electronic fetal monitor, interpretation, competence, training, evaluation, interprofessional

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CHAPTER 1
INTRODUCTION

I began my nursing career in 1986 after completing a bachelor of nursing program at a small midwestern university. Upon graduation, I worked in a level-three neonatal intensive care unit (NICU) at a regional hospital that consistently maintained a high census and patient acuity. Out of necessity, I transformed into an expert NICU nurse over my first few years. Developing NICU expertise required caring for infants with multiple comorbidities and communicating effectively in a high-acuity team setting. At the time, I could not conceive how the infants and families I encountered during this early stage of my nursing career would influence the unfolding of my professional journey. Nevertheless, the memories I carry from early in my nursing career continue to nurture my passion for the profession and research focused on interprofessional competence in interpretation of electronic fetal monitoring (EFM) tracings.

The infants for whom I cared in the NICU were primarily born prematurely, requiring specialized care and health care technologies to sustain life. However, another population of babies I encountered remains a concern and inspires my research aimed at preventing poor neonatal outcomes. The poor effects these infants experienced did not result from premature birth but from an intrapartum event resulting in birth asphyxia, commonly referred to as hypoxic-ischemic encephalopathy (HIE). LaRosa et al. (2017) estimated around four million neonates experience birth asphyxia annually worldwide, primarily resulting from events occurring during the intrapartum period. Out of these four million cases, approximately 1.2 million deaths result and infants who do not die during birth present with brain damage and other multi-organ comorbidities.

I found it challenging to care for newborns with HIE, not because of the nursing expertise required to care for their physiological well-being, but rather the extensive emotional energy exerted knowing these irreversible birth outcomes were often preventable. As a result, my early career memories remain fresh, even though over thirty years have passed since I first cared for these tiny patients. Nonetheless, the current state of my professional nursing journey presents an opportunity to address HIE outcomes by establishing foundational work to research a likely cause of HIE discovered in the literature—inadequate competence in the interpretation of EFM tracings by both nurses and physicians. This dissertation study is a preliminary project to establish a foundation of research in this area by assessing the feasibility of an innovative educational intervention to improve competence in interpretation of EFM tracings by registered nurses, nurse midwives, residents, and physicians. My future research program will further test the efficacy of this approach and identify if improved competence in interpretation of EFM tracings also affects neonatal outcomes.

Introduction to the Research Problem

In the United States (U.S.), the infant mortality rate is 5.8 deaths for every 1000 live births (CDC, 2017). As I began investigating why national neonatal outcomes have failed to improve in the U.S., I discovered previously identified human-error issues surrounding interpreting EFM tracings as a diagnostic health care technology during intrapartum care. Adequate care of a mother during labor includes managing the mother's physiological and emotional state, supporting labor progression, and assessing the physiological well-being of the unborn child. Evaluation of the neonate during the intrapartum period occurs through intermittent auscultation of the neonatal heartbeat or integrating EFM. Development of EFM was intended to decrease adverse neonatal outcomes; however, this anticipated impact failed to materialize. Researchers who aimed to discover why EFM did not result in improved neonatal outcomes identified issues related to clinical competence in interpretation of EFM tracings, primarily regarding how nurses and physicians receive training and how competency is evaluated (Santo et al., 2012; Kelly et al., 2021; Sabiani et al., 2015).

Electronic fetal monitors provide obstetric team members with essential physiological data to identify the rate and response of fetal heart tones related to uterine contractions. All mothers do not experience the application of EFM during labor. Whether to use EFM mostly depends upon the clinical acuity of the mother and fetus (Berkowitz et al., 2014). Declercq et al. (2007) identified the most current estimated rate of women who receive continuous use of EFM during intrapartum care in the U.S. at 87%.

Nurses and physicians interpret tracing data from EFM generated during the intrapartum period. A primary issue with interpretation of these data includes inaccuracies and inconsistencies by members of the obstetric team, including physicians, residents, nurse midwives, and registered nurses, either individually or as a team (Santo et al., 2012; Sabiani et al., 2015; Clark et al., 2013; Nzelu et al., 2018). Nurses primarily perform front-line interpretations of EFM tracings; however, unlike nurses who are mainly at the bedside, physicians are often not directly in the clinical setting when concerning tracings are present and rely on nurses to communicate these concerning tracings (Sandelowski, 2000).

When EFM initially emerged in obstetric care, training to interpret EFM tracings only occurred for physicians, even though both nurses and physicians used EFM to identify fetal distress during the intrapartum period (Sandelowski, 2000). Nurses and physicians receive training in interpretation of EFM tracings through academic or clinical preparation. Nonetheless, these training methods often lack thoroughness to ensure initial competence and maintenance of competence over time (Kelly et al., 2021). Furthermore, not establishing competence in interpretation of EFM tracings not only results in individual human errors in interpretations, but also leads to care disagreements that may prohibit interventions that could potentially prevent adverse neonatal outcomes (Sabiani et al., 2015; Clark et al., 2013; Chen et al., 2011; Ross et al., 2019). Therefore, future research must identify the essential personnel required to receive training and evaluations in EFM use, the most effective training and assessment methods to be used, and the appropriate frequency of training and evaluation to attain and maintain competence (Kelly et al., 2021).

Promoting improved competence in interpreting tracings from EFM must also be planned to enhance intra- and inter-rater consistencies (Govindappagari et al., 2015; ACOG, 2005; Nzelu et al., 2018). Reimagined training and evaluation methods for interpretation of EFM tracings should identify individual weaknesses in interpretation, provide an opportunity for deliberate practice (D.P.) guided by an individual learner's needs, and confirm competence through evidence-based evaluation tools. Integrating clinical training and evaluation methods using simulation-based mastery learning (SBML) with D.P. modalities that realistically mimic clinical environments improve clinical competence and support the transfer of learned behaviors to clinical practice (McGaghie et al., 2011; McGaghie et al., 2015; McGaghie et al., 2020). An application called the Simulated Electronic Fetal Monitor (SEFM), developed by researchers from the Health Innovation in Technology and Simulation (HITS) lab at the University of Tennessee, addresses the lack of educational tools to effectively mimic, train, and confirm competence in interpretation of tracings from EFM through an innovative simulation modality (Wyatt et al., 2015). The SEFM also includes an Electronic Fetal Monitor Competence Evaluation Tool (EFM-CET) used for self-, formative, and summative evaluation of competence.

Through the literature review and concept analysis presented in Chapters Two and Three, respectively, the following research questions were developed and explored in this dissertation:

- Do relationships exist between obstetric health care professionals' demographic characteristics, including (1) type of previously completed EFM training, (2) EFM certification status, (3) clinical role, (4) amount of clinical experience, and (5) amount of labor and delivery experience and competence in interpretation of EFM tracings?
- What is the feasibility and efficacy of an innovative simulation educational intervention in educating, evaluating, improving intra- and interrater interpretation consistencies, and promoting sustained competence in interpreting EFM tracings?

Research Aims

The following aims and hypotheses addressed the research questions:

Aim 1: Evaluate the feasibility of participants to engage in a SBML with DP intervention in a clinical workplace setting.

Hypothesis 1: Participants will evaluate the SBML intervention as feasible for training, evaluating, and sustaining competence in interpreting tracings from EFMs.

Aim 2: Determine how obstetric nurses’ and physicians’ characteristics (differences in level and type of education, years of obstetric experience, years of clinical experience, previous training, and certification status) affect baseline scores of interpretations from EFM tracings.

Hypothesis 2: Participants with higher levels of education, more years of obstetric and clinical experience, and previous training and certification in EFM will demonstrate higher baseline scores.

Aim 3: Evaluate the effects of a SBML with DP intervention compared with clinical experience alone on competence scores and intra- and interrater consistency of interpretations of EFM tracings immediately following and three months post-intervention.

Hypothesis 3: Participants will display improved competence in interpretation of tracings from EFM following a SBML with DP intervention using the EFM-CET from pre- to post-intervention and sustain competence three months post-intervention compared with clinical experience alone.

Hypothesis 4: Participants receiving a SBML with DP intervention will be more accurate in their interpretations of categorizations (Category I, II, & III) of EFM tracings immediately following and three months post-intervention using the EFM-CET compared with participants having clinical experience alone.

Aim 4: Evaluate the impact of a SBML with DP intervention on participants' levels of self-efficacy in the interpretation of tracings from EFM.

Hypothesis 5: Participants' levels of self-efficacy in competence in interpretation of tracings from EFM will improve following the intervention as measured using an adapted version of the Healthcare Technology Self-Efficacy (HTSE) tool (Rahman et al., 2016).

Significance

This project holds significance by exploring an innovative training and evaluation process to ensure obstetric caregivers are competent to interpret EFM tracings accurately. By doing so, the research also promotes practice-readiness to assess, recognize, and intervene when the physiological status of the fetus declines. Additionally, the study outcomes provide an opportunity to reimagine learning and evaluation approaches to interpretation of EFM tracings regarding the SBML with D.P. intervention design in terms of feasibility and evaluation.

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CHAPTER II
LITERATURE REVIEW

A Scoping Review to Assess Education and Evaluation of Electronic Fetal Monitor Interpretation

This article has not been published, nor will it be before I submit the final version into the Tennessee Research and Creative Exchange (TRACE). However, the formatting for this manuscript is based on author guidelines for the *Journal of Obstetric, Gynecologic, and Neonatal Nursing (JOGNN)*.

I developed the initial draft of this manuscript with sole authorship for my Ph.D. comprehensive exam in spring 2021. Drs. Joel Anderson, Tami Wyatt, and Suzan Kardong-Edgren provided feedback on the initial draft, and Dr. Joel Anderson offered additional feedback and editing to finalize the manuscript. The manuscript was submitted and denied publication in summer 2022 to JOGNN. Following completion of this dissertation, I plan to resubmit the manuscript to a journal to be identified at a later date.

Abstract

Objective: To evaluate literature on the current state of electronic fetal monitoring (EFM) education and competence evaluation, specifically in the interpretation of EFM tracings. **Data Sources:** A systematic search was conducted of peer-reviewed articles published between May 2011 to 2021 using CINAHL, PubMed, and Web of Science databases. Included articles contained research findings on EFM training and competence evaluation and engaged participants with responsibilities for EFM interpretation. **Study Selection:** Duplicate publications and non-research publications were removed, and all studies containing any aspect of education and/or evaluation of EFM interpretation were retained for the analysis. **Data Extraction:** A total of 192 initial publications were identified; however, only eight met criteria for the final analysis. Data extracted from each publication included study type, research setting, participant professional role, and topics aligned with best practices in curricular design, learner evaluation, and interpretation of EFM tracings. **Data Synthesis:** The publications represented experimental (*n*=3) and quasi-experimental (*n*=4) studies, and one on the reliability of an EFM certification evaluation. All but one contained educational interventions and the researcher's reported effects on participants' EFM knowledge (*n*=5), clinical performance (*n*=1), or clinical outcomes (*n*=1). Three reports contained a theoretical education framework in the intervention or evaluation design. Out of the seven interventional studies, the most common intervention was e-learning alone or a hybrid method including e-learning (*n*=6). An evaluation tool measured effectiveness in most studies (*n*=6); however, of these, three confirmed EFM competence by setting passing standards. Some researchers operationalized tools conveying statistical rigor (*n*=3), one group measured the essential components of EFM interpretations, and another considered interrater consistencies of participants' EFM interpretations. **Conclusion:** The findings of this review establish the need to improve the routine practice of EFM interpretation training and evaluation. This includes integrating the evidenced-based practices of educational design, learner evaluation, and EFM interpretation.

Keywords: electronic fetal monitor, interpretation, education, training, evaluation, scoping review

Précis Statement: This review establishes a need for improved EFM interpretation training and evaluation practices. This includes integrating best practices of educational design, learner evaluation, and EFM interpretation.

A Scoping Review to Assess Education and Evaluation of the Interpretation of Electronic Fetal Monitor Tracings

Infant mortality in the United States (U.S.) remains concerning, with 5.8 neonatal deaths for every 1000 live births (CDC, 2017; Jacob, 2016). Globally, intrapartum-related birth complications account for approximately one-third of neonatal deaths annually (World Health Organization, 2020). Electronic fetal monitors (EFMs) generate readable tracings that, if interpreted accurately, provide data to inform interventions aimed at decreasing the incidence of adverse neonatal outcomes (Ayres-de-Campos, 2016). In the U.S., EFMs are integrated into the care of 87% of laboring mothers (Berkowitz et al., 2014). Nonetheless, use of EFM technology has not translated into positive neonatal outcomes (Declercq et al., 2007), and suboptimal interpretation of EFM tracings to help identify fetal distress is a root cause of perinatal death (Chauhan et al., 2008; Chen et al., 2011; Ross, 2019). Without accurate interpretations of EFM tracings by health care providers, decisions to support the well-being of the fetus cannot be made (Santo & Ayres-de-Campos, 2012; Chen et al., 2011; Clark et al., 2013). Makary and Daniel (2016) estimated human error as the third leading cause of death in the U.S. Inaccuracies in interpretations of EFM tracings are potential reasons why EFM does not translate to a decreased incidence of perinatal death (Sabiani et al., 2015; Santo et al., 2012; Chen et al., 2011).

Parameters monitored on EFM tracings include baseline fetal heart rate (FHR), baseline heart rate variability, the presence of accelerations and decelerations in heart rate, and types of decelerations (National Institute of Child Health and Human Development [NICHD], (1997). Interpretation of FHR patterns requires knowledge to recognize the complex relationship between the FHR and maternal contractions. Overall variability (Govindappagari et al., 2016) and late decelerations (Sweha & Hacker, 1999) of FHR patterns are the parameters most crucially noted to correlate with concerning EFM tracings, such as Category II or III tracings that require crucial interventional care measures promptly. In 1997, the National Institute of Child and Human Development developed guidelines to classify interpretation of EFM tracings in an effort to improve neonatal outcomes; these were updated to include categorization in 2008 (NICHD, 1997; Macones et al., 2008). However, in application of the interpretation criteria since inception, these initiatives failed to substantially improve neonatal outcomes (Chen et al., 2011; Clark et al., 2013; Ross, 2019). Research suggests the interpretation classification system failed to produce improved neonatal outcomes because guidelines were not fully understood and no governing body ensured the quality of trainings or evaluations to sustain competence of obstetric personnel in interpretation of EFM tracings (Ugwumadu et al., 2016; Kelly et al., 2021)

Research identifying the effectiveness of obstetric safety initiatives, including obstetric training and evaluation processes, resulted in decreased adverse events (Clark et al., 2011; Pettker et al., 2014) and liability claims (Pettker et al., 2014). However, neither intervention focused solely on training and evaluation of interpretation of EFM tracings; thus, it is unknown which elements led to improved outcomes. Additionally, far-reaching guidelines and feasible strategies to inform policies and programs specifically to teach, evaluate, and sustain competence is lacking.

Kelly et al. (2021) recently completed a meta-analysis on training in the use of EFMs and organized results into three categories: training methods, impact of training, and training as part of a more extensive intervention. The review comprised 64 primary research publications examining the impact of intrapartum training in the use of EFMs and were included irrespective of study design, published language, or date of publication. The researchers reported overall content and methods for delivering EFM training were generally poor and better quality studies were warranted. Future studies should include improved research designs, interventions, and evaluation methods with innovative educational methods and guidelines for evaluation.

The literature review by Kelly et al. (2021) provides crucial new data about training and evaluation regarding EFMs. However, the authors overlooked (1) the breadth of study settings and clinical environments to provide a global perspective; (2) the educational modalities and methods used in curricular development; (3) the presence or absence of educational theories or frameworks used in the development of trainings; (4) the specific EFM factors evaluated and the rigor of the evaluation measures used; (5) the inclusion of an operationalized definition of competence in interpretation of EFM tracings; and (6) the inclusion of intra- and/or interrater consistencies in interpretation. Therefore, the purpose of the present literature review is to examine the current state of education and competence evaluation for interpretation of EFM tracings to understand these additional aspects, as well as the strengths and weaknesses of educational methods and evaluation measures for interpreting EFM tracings. This analysis will also offer recommendations to guide future research related to interpretation competence when EFMs are used.

Methods

This integrative scoping review was documented using the preferred reporting items for systematic reviews (PRISMA) guidelines (Moher et al., 2009).

Eligibility Criteria

All publications that examined methods of education, evaluation, or competence in EFM use among multi-disciplinary health care teams were eligible for inclusion, regardless of study design. Publications included were those that (1) reported findings from research on training and competence evaluation of EFMs, (2) included participants holding primary responsibility for interpretation of EFM tracings, (3) were published in English in a peer-reviewed journal, and (4) were published within ten years preceding the search completed in May 2021. The literature search was conducted with assistance from two health science librarians from the University of Tennessee, Knoxville. Boolean search terms and connectors included keyword word building blocks for all databases and MeSH terms for searching PubMed. The searched databases included CINAHL, PubMed, and Web of Science. The following keyword building blocks and MeSH terms were used for all databases: (1) electronic fetal monitor*, electronic fetal surveillance, intrapartum fetal monitor*, intrapartum fetal surveillance, fetal heart monitor*, or cartiotocogra*; (2) use or interpret*, read* or translat*, understand*, evaluat*, or assess*; (3) nurs*, physician*, doctor*, clinician*, resident*, provider*, or obstetri*; and (4) competen*, capab*, abilit*, proficien*, skill*, knowledg*, expert*, or adequa*.

Results

Study Selection and Characteristics

Initial searches gathered 60 articles from CINAHL, 118 from PubMed, and 42 from Web of Science. After removing duplicate reports, 192 remained and were further reviewed. Of these, 162 were excluded because these did not meet inclusion criteria, leaving 30 for the next phase of the review. See Figure II.1 for the PRISMA flowchart (All tables and figures are located in the appendices).

Independent screening of the 30 resulting publications was completed to ensure all final publications included information about current practices for education and evaluation of interpretations of EFM tracings. During this phase, publications were removed if unrelated to the specific topic of EFM training and education or evaluation (*n*=10) or not based on research (*n*=12). The final screening resulted in eight articles deemed appropriate for the review (Table II.1).

The publications included represented studies that were experimental (*n*=3) (Carbonne & Sabri-Kaci, 2015; Jomeen et al., 2019; Keegan et al., 2016) or quasi-experimental (*n*=4) (Cusanza et al., 2021; Govindapaggari et al., 2016; Thellesen et al., 2017; Wagner et al., 2012) in design, as well as one report of the reliability of an EFM credentialing evaluation (*n*=1) (Tomlinson et al., 2020). The majority included interventional training results of participants' knowledge of EFMs (*n*=5) (Carbonne & Sabri-Kaci, 2015; Cusanza at al., 2021; Jomeen et al., 2019; Keegan et al., 2016; Thellesen et al., 2017); however, one group of researchers also measured clinical performance (Govindappagari et al., 2016) while another evaluated clinical outcomes (Wagner et al., 2012).

Study Participants and Settings

Two studies focused primarily on the nurse's role in interpretation of EFM tracings (Keegan et al., 2016; Cusanza et al., 2020), while the remaining six included multi-disciplinary team members. The studies involving multi-disciplinary teams mostly incorporated only nurses and physicians (Govindappagari et al., 2016; Carbonne & Sabri-Kaci, 2016; Thellesen et al., 2017; Tomlinson et al., 2020), although two studies engaged a broader professional scope, including anesthesiologists, neonatologists (Wagner et al., 2011), and paramedics (Jomeen et al., 2020).

Data Synthesis

The reviewed publications included studies conducted in inpatient obstetric facilities in the southern (Cusanza et al., 2020) and northeastern (Govindappagari et al., 2016; Wagner et al., 2011) regions of the U.S., as well as France (Carbonne & Sabri-Kaci, 2016) and Denmark

(Thellesen et al., 2017). One study engaged community providers across the United Kingdom (Jomeen et al., 2020). The remaining two studies did not occur in clinical settings. The study by Keegan et al. (2016) occurred in an academic nursing program in the northeastern U.S., while Tomlinson et al. (2020) analyzed the reliability of a national EFM certification exam.

From the five studies conducted in inpatient clinical settings, two represented a solitary site (Wagner et al., 2011; Govindappagari et al., 2016) and three used a multi-site approach (Carbonne & Sabri-Kaci, 2016; Cusanza et al., 2020; Thellesen et al., 2017). The single-site studies both involved large medical centers in New York and were developed to evaluate center-specific educational interventions prompted by identified needs to improve obstetric outcomes at these facilities. Wagner et al. (2011) did not include the number of participants because only post-intervention documentation from medical charts was captured. Rather, the researchers reported odds ratios for maternal adverse outcome indicators (MAOIs) across calendar quarters in the years 2008 and 2009. The number of charts reviewed in each quarter ranged from 1235 during the first quarter of 2009 to 1398 during the second quarter of 2008. Govindappagari et al. (2016) recruited 200 registered nurses and 228 physicians from one hospital. The three multi-site publications included a study by Cusanza et al. (2020) conducted at three hospitals in the southern U.S. (n=55 participants), the study by Carbonne and Sabri-Kaci (2016) involving five maternity departments in Paris (n=75 nurses, n=38 physicians), and the study by Thellesen et al. (2017) evaluating 24 maternity units in Denmark (n=269 obstetricians, n=1260 nurse midwives, n=142 obstetric residents).

Educational Methods and Curriculum Development

Educational and Evaluation Methods Used

Seven of the eight publications included the type of training to promote competence in interpretation of EFM tracings, yet several lacked details to describe the educational methods adequately. The most common educational interventions were online asynchronous e-learning modules (Govindappagari et al., 2016; Carbonne & Sabri-Kaci, 2015; Cusanza et al., 2020). Two training programs also involved a hybrid or a combination of e-learning modules and facilitated face-to-face interventions (Thellesen et al., 2017; Wagner et al., 2012). One reported using simulation-based scenarios (Wagner et al., 2012) and another integrated a one-day, face-to-face course with lectures, discussions, and small-group teaching (Thellesen et al., 2017). Keegan et al. (2016) incorporated a unique simulated application specific for EFM training, the WholeLogic® SimLet, as the interventional modality; however, the researchers did not describe the processes and rigor of the application development or design. Only one group described using a traditional lecture format for a one-day, face-to-face training (Jomeen et al., 2019).

Each study included some form of evaluation to assess the effectiveness of an educational intervention on either knowledge of EFMs, clinical performance, or clinical outcomes. Most used a participant competency evaluation to determine training effectiveness (Thellesen et al., 2017; Carbonne & Sabri-Kaci, 2015; Wagner et al., 2012; Keegan et al., 2016; Jomeen et al., 2019; Cusanza et al., 2020), but only three studies (Thellesen et al., 2016; Cusanza et al., 2020; Wagner et al., 2012) operationalized a previously researched and validated evaluation tool conveying statistical rigor of the measures. Cusanza et al. (2020) reported construct validity/internal consistency and reliability of the tool (Cronbach's alpha = 0.99) to measure areas of risk management concerns including cognition, communication, performance, professionalism, and the obstetric care system. Thellesen et al. (2016) incorporated a measure to evaluate knowledge of EFMs, interpretation skills, and decision making and reported the tool fitted a loglinear Rasch model to discriminate levels of competence in interpretation of EFM tracings. The tool used by Wagner et al. (2012) captured MAOIs and was previously researched for item development and appropriateness (Mann et al., 2006).

The study by Govindappagari et al. (2016) integrated a comprehensive chart review regarding consistencies between nurses' and physicians' documentation of interpretations using an evidence-based rubric rather than participant interpretation accuracies to measure effectiveness. The study by Tomlinson et al. (2020) did not include an intervention but rather, evaluated an EFM certification exam to ensure the tool produced valid data to measure interpretation knowledge and clinical judgment before awarding EFM credentialing.

Inclusion of Essential EFM Interpretation Components in Competence Evaluation

All eight studies in this review were evaluated to determine whether researchers considered the essential components for interpretation of EFM tracings, including baseline FHR, baseline heart rate variability, existing accelerations or decelerations in FHR, types of decelerations, and tracing classification. Keegan et al. (2016) and Wagner et al. (2012) did not report whether components of EFM tracings were present in the study intervention or evaluation. Thellesen et al. (2017), Carbonne and Sabri-Kaci (2016), Tomlinson et al. (2020), and Cusanza et al. (2020) detailed EFM classification as a training and evaluation factor, yet did not share specific information regarding the essential components of interpretation of EFM tracings. Govindappagari et al. (2016) involved all elements of interpretation of EFM tracings in both training and evaluation except for tracing classification. Jomeen et al. (2020) based evaluation only on the physiological causes of tracing patterns but did not share if evaluations also required interpretations of the EFM tracing components listed above.

Processes for Development of Curricula

Diverse curricular development processes were used to create the interventional content of the reviewed studies. Only Thellesen et al. (2017) described a needs-based approach to identify learning objectives of the intervention by engaging national content experts in a Delphi study. Jomeen et al. (2019) reported using a previously developed cardiotocography (CTG) masterclass from an outside organization called Neoventa. Two others, Govindappagari et al. (2016) and Wagner et al. (2012), included risk-management identifiers to direct the content of the educational intervention. Keegan et al. (2016) and Cusanza et al. (2020) did not discuss how the intervention curriculum was developed.

Use of an Educational Theoretical Framework

The presence or absence of an educational framework to guide the EFM educational training interventions and competence measurement tools was also evaluated. Only three studies (Cusanza et al., 2020; Keegan et al., 2016; Tomlinson et al., 2020; Thellesen et al., 2017) included an educational theory, learning framework, or evaluation-based theory to guide the intervention or outcome measures, with each using a different theory. Cusanza et al. (2020) designed an educational intervention explicitly guided by a motivational learning framework by Moore et al. (2009), which proposes five stages exist in health practitioners' learning: (1) recognizing learning opportunities, (2) searching for resources to aid the learning process, (3) engaging in learning, (4) trying out what was learned, and (5) integrating learning in clinical practice. Keegan et al. (2016) deployed active learning techniques (Prince, 2004) and Just-in-Time Teaching (Novak et al., 1999) strategies to guide development of an interventional learning application. Thellesen et al. (2017) described engaging a test development theory to construct an evaluation measure, while Tomlinson et al. (2020) used the Script Concordance Theory and Item Response Theory (Charlin et al., 1998) to measure participants' clinical knowledge related to clinical actions, estimating difficulty in the assessment, and discriminating competence between examinees. Of the two studies (Cusanza et al., 2020; Keegan et al., 2016) that included an educational framework in the intervention design, only Cusanza et al. (2020) integrated concepts of motivational learning that revealed significant improvements for practicing registered nurses from pre- (76.7, SD=9.12) to post-intervention (82.5, SD=6.9; p=0.008).

Definition of Competence Using EFMs

Only three studies (Tomlinson et al., 2020; Cusanza et al., 2020; Thellesen et al., 2017) established participant passing standards in the evaluation measures to confirm competence in using EFMs. Tomlinson et al. (2020) employed a previously determined passing score on the Perinatal Quality Foundation credentialing exam. In the study by Cusanza et al. (2020), achieving a 100% passing score on the evaluation tool indicated conceptual knowledge of EFMs. Thellesen et al. (2017) developed and validated a 30-item test requiring 25 correct responses to convey competence in interpretation of EFM tracings. Researchers in four of the eight studies (Carbonne et al., 2015; Keegan et al., 2016; Jomeen et al., 2019; Wagner et al., 2012) did not set minimum passing scores or define competence. See Table II.2 for the reported study criteria for training and evaluation methods analyzed.

Effectiveness of Educational Interventions and Evaluation Measures

The publications included in this review examined training effectiveness with the exception of the certification tool used by Tomlinson et al. (2020). By and large, the research teams reported success in the educational interventions employed. Multiple studies showed positive outcomes related to e-learning interventions. For example, Carbonne and Sabri-Kaci

(2016) reported post-intervention scores on evaluations of EFM knowledge were significantly higher in an e-learning training group (37.1 ± 5.5) versus a group receiving no training (32.6 ± 5.7; p=0.0026). Additionally, participants spending more than four hours on the modules (38.9 ± 5.4) performed significantly better than those engaging in the content for fewer than four hours (31.3 ± 3.7; p < 0.005). Keegan et al. (2016) also found that learners using a mobile e-learning application displayed significantly (p<0.01) improved mean scores (85%) on a post-intervention quiz than students who completed traditional learning methods, including only required readings (70%).

Other studies also reported successful operationalization of e-learning. Of these, Cusanza et al. (2020) found significantly improved participant outcomes in interpretation of EFM tracings from pre- (76.7 ± 9.12) to post-intervention (82.5 ± 6.9; p=0.008). Additionally, Govindappagari et al. (2016) reported improved interpretation consistencies following an e-learning intervention between physicians' and nurses' documentations of EFM tracings regarding heart rate variability and accelerations upon admission (agreement on variability: 91.1% vs. 98.3%, p<0.001; and agreement on accelerations: 75.2% vs. 87.7%, p<0.001), and at the time immediately prior to delivery (agreement on variability: 82.1% vs. 90.6%, p=0.001; agreement on accelerations: 56.7% vs. 68.6%, p=0.0012).

The remaining studies used a combination of educational methods. Thellesen et al. (2017) employed an intervention comprised of e-learning and face-to-face training. The multi-faceted intervention by Wagner et al. (2011) included Team Strategy and Tools to Enhance Performance and Patient Safety training (Team STEPPS)(Agency for Healthcare Research and Quality, 2010), interdisciplinary teaching rounds, and an EFM educational e-learning course. Finally, Jomeen et al. (2020) operationalized an educational intervention involving a face-to-face instructional session focused on use of EFM interpretation and a hands-on practical session to manage obstetric emergencies in community settings.

Thellesen et al. (2017), Wagner et al. (2011), and Jomeen et al. (2020) each reported positive outcomes for participants' knowledge of EFMs. In each study, the researchers incorporated unique outcome measures to test the effectiveness of the intervention. Thellesen et al. (2017) assessed correlations between participants' demographic characteristics and features of the clinical settings with enhanced conceptual knowledge, interpretation of EFM tracings, and clinical decision making in relation to EFM tracings following an intervention combining e-learning with an in-person course. They found participants from hospitals with more than 3000 annual deliveries displayed significantly ($p=0.006$) higher knowledge of EFMs, interpretation accuracy, and overall skill than those working at hospitals with fewer than 1000 annual deliveries. Additionally, participants with fewer than 15 years of clinical experience performed significantly better ($p=0.007$) than those with more than 15 years. Wagner et al. (2011) gathered data post-intervention (a combined modality Perinatal Safety Initiative) on participants' scores related to MAOIs to determine the effects of their multi-faceted intervention. The MAOIs captured included maternal (i.e., maternal death, admitted to higher-level care, uterine rupture, peripartum hysterectomy, and return to operating room), fetal, and neonatal (i.e., stillbirth, neonatal death, 5-minute APGAR <7, iatrogenic prematurity, and birth trauma) indicators. Regression analysis revealed, overall, the MAOIs significantly decreased ($p<0.004$) from year one (2%) to year two (0.08%) following the intervention. However, the only individual MAOI improvements with rate reductions were the maternal return to the operating room ($p<0.018$) and fewer birth traumas ($p<0.0022$).

Inclusion of Intra- and Interrater Consistencies of Interpretations

Only Govindappagari et al. (2016) measured the effectiveness of training on the interrater consistency of interpretations between registered nurses and physicians. In that study, researchers analyzed documentations of tracing interpretations from 701 charts (n=351 charts from pre-intervention and n=350 charts post-intervention) to achieve 80% power with a p-value <0.05. They found overall interpretation consistency significantly (p<0.001) improved between nurses and physicians following the intervention (before = 91.1% agreement; after = 98.3% agreement). Additionally, pre- to post-intervention documentations of the FHR variability (91.1 % vs. 98.3%, p<.0.001) and accelerations (75.2 % vs. 87.7%, p<0.001) revealed significant improvement of nurse and physician consistency within the interpretations on admission . Interpretation of tracings immediately prior to delivery were also enhanced in the post-intervention chart reviews (variability: 82.1% vs. 90.6%, p=0.001; accelerations: 56.7% vs. 68.6%, p=0.0012). Nonetheless, significant improvement in the consistency of interpretations of decelerations was lacking. It warrants highlighting these researchers did not evaluate the accuracy of the interpretation documentation and only focused on the consistency of interpretations of EFM tracings between nurses and physicians. Finally, three studies captured overall post-intervention effectiveness longitudinally from three months (Carbonne & Sabri-Kaci, 2015; Jomeen et al., 2019) to two years (Wagner et al., 2012). However, no data were gathered or reported to determine if the interventions affected consistency of intra- or interrater interpretations of EFM tracings over time.

Discussion

There are variations in education and evaluation practices of EFM use reported in the literature. These variations include (1) use of educational-theory-driven EFM training interventions and evaluation measurements of EFM competence, (2) the types of training and evaluation modalities used, (3) the rigor of the educational interventions and evaluation measures, (4) the effectiveness of the educational interventions on competence in interpretation of EFM tracings and intra- and interrater consistencies of these interpretations, (5) the clinical roles of the included study participants, (6) the research settings, and (7) whether an operationalized definition discriminated between attaining or not attaining competence.

Thellesen et al. (2017) uniquely developed a survey to measure correlations between demographic characteristics of obstetric personnel including nurse midwives, resident physicians, and obstetric physicians to determine predictive factors of EFM competence. Surprisingly, obstetric professionals with more than 15 years of clinical experience scored significantly lower on overall level of competence compared with professionals with fewer than 15 years of experience. These findings contradict a common belief that more experience leads to higher levels of competence. Benner's (2001) *From Novice to Expert* nursing theory explains that nurses attain clinical competence through a trajectory of career stages as clinical experience accumulates over time. However, Ericsson and Pool (2016) found attainment of competence does not necessarily require extended amounts of time but is rather secured through deliberate practice prompted by a motivated learner, individualized instruction, and guided learning with an expert in the field. Their findings reveal an inverse relationship between experience and sustained competence and, therefore, call for future research to identify recommendations to determine timeframes for repeated evaluations of competence in essential skills. Thus, additional longitudinal research to identify adequate timing of repeated training and evaluation of EFM-tracing interpretation is essential.

The studies in this review represent a limited international focus (U.S. and Europe) on training and evaluation practices for EFMs. In 2010, the World Health Organization (2010) established an intentional goal to improve intrapartum care worldwide and subsequently decrease rates of preventable maternal and neonatal deaths. This initiative resulted in increased use of EFMs. Recent market analyses reveal expected increases in international market growth of EFMs from $2.8 billion to $4.2 billion between 2019 and 2025, with the largest increases anticipated in the U.S., China, Japan, Canada, and Germany (Report Linker, 2021). However, of the countries with the greatest projected increases in EFM use, only literature from the U.S. could be found to include in this review. Newly developed, low-cost technologies aimed towards low-resource countries, such as the novel continuous fetal doppler by Kamlea et al. (2018), are emerging due to the recent push to improve maternal and neonatal outcomes worldwide. In comparison, delivery models of intrapartum care significantly differ between high- and low-resource countries. These differences are mostly based on available obstetric resources such as trained birth attendants and intrapartum services including health care technologies (WHO, 2010; Bhutta et al., 2009). However, even though low-resource countries desire to adopt birth technologies such as EFMs, the implementation processes necessary to train personnel in these countries, including clinical experts to provide trainings, are mostly not feasible (Fauveau et al., 2008; Dogba et al., 2009; Kamela et al., 2018). Thus, increasing the international representation of EFM training and evaluation research, is warranted to identify unknown issues in the integration of EFMs, especially in areas newly adopting such technology. It should be noted that the absence of literature in this review from low-resource countries could be the result of only including research published in English.

Use of EFMs that includes tracing interpretation is a fundamental competency for all clinicians providing care to laboring mothers (AWHONN, 2015). Thus, research promoting enhanced competence of obstetric personnel using EFMs should engage all those in clinical roles with the potential to interpret EFM tracings, such as anesthesiologists who monitor the fetus during obstetric surgical procedures. Ensuring all personnel obtain and sustain competence improves the preparedness of the obstetric team to respond with the highest level of care to protect the safety of mothers and their infants when an unexpected sentinel obstetric event occurs. At the very least, training and evaluation of competence in interpretation of EFM tracings must include nurses and physicians with primary responsibilities for interpreting these tracings. Several of the studies reviewed included interprofessional obstetric teams and, if possible, future research must include similar inclusive participant populations.

The use of educational theory to guide the interventions reported in the reviewed studies is, for the most part, absent. This creates a gap in the science because evidenced-based clinical education promotes positive outcomes, such as those found by Moore et al. (2009) when using motivational learning based on social cognitive theory. A unique feature of motivational learning is identifying an individual’s needed areas of improvement, which also serves to motivate learners why improvements are necessary related to the consequences of lacking knowledge or skill (Bandura, 1986). Additionally, adopting best practices of workplace learning, including summative evaluation, translates to individual employee competence and workplace excellence (Rowden, 2007). Yet, only the study by Cusanza et al. (2020) integrated a workplace learning design by using an individualized needs-based intervention, a known foundational best practice for workplace learning (Rowden, 2007). This study by Cusanza et al. (2020) could serve as a model to guide future research that integrates both social cognitive/motivational learning and workplace learning.

Although several studies reported longitudinal measurement of training effectiveness, the lack of evidence to support sustained EFM competence remains. Study outcomes may have been enhanced further if educational theories known to support sustained learning were included in study methodologies. Longitudinal studies incorporating a simulation-based, mastery-learning theoretical approach for clinical training have resulted in improved retention of clinical skills over extended periods of time and include concepts of social cognitive theory and workplace learning (McGaghie et al., 2020; Wayne et al., 2006; Barsuk et al., 2010; Moazed et al., 2013). Assuring sustained clinical competence in interpretation of EFM tracings is essential considering the effects on maternal and neonatal outcomes resulting from the critical decisions obstetric professionals make using these tracings while caring for laboring mothers.

The EFM competence measurement tools reviewed were diverse and each tool served a specific purpose either to confirm competence in conceptual knowledge of EFMs or interpretation of EFM tracings. The studies evaluating only conceptual knowledge of EFMs without concurrent confirmation of competence in interpretation of EFM tracings are questionable considering the importance of interrater consistency to guide key decisions in intrapartum care interventions among members of the obstetric health care team. Surprisingly, only four of the eight studies (Keegan et al., 2016; Thellesen et al., 2017; Tomlinson et al., 2020; Govindappagari et al., 2016) integrated realistic live-feed tracings in evaluation of competence. Educational interventions and evaluations must integrate interpretation of realistic tracings to promote translation of competence to clinical practice. Also, only Cusanza et al. (2020) initiated a 100% passing rate on the EFM competence evaluation; this evaluation was comprised solely of conceptual knowledge without actual interpretation of tracings. An example of conceptual knowledge is the physiological cause of a tracing, yet this does not provide assurance there is an understanding of the critical care decisions in response to the cause or foundational competence to interpret EFM tracings. Additionally, if obstetric professionals are only required to convey conceptual knowledge without having foundational competence in interpretation of EFM tracings, appropriate clinical interventions in response to the interpretation are questionable. For this reason, the researchers of several of the reviewed studies recommend ongoing education and evaluation methods that comprise the foundational skill of competence in interpretation of EFM tracings.

E-learning incorporated into most of the educational methods used in the reviewed studies resulted in positive overall results to enhance competence. Additionally, e-learning modalities hold the most potential to transfer competence to actual clinical settings by having a feasible platform to deliver live-feed EFM tracings and increase access to content for asynchronous and synchronous learning. However, Carbonne and Sabri-Kaci (2016) reported participants had ideal outcomes when four or more hours were spent on the e-learning modules, which is most likely not feasible considering the time needed for personnel to be away from the work setting. A study by Murphy et al. (2003) reported evaluations of EFM competence occurred primarily through supervised clinical evaluations. This is also a concern because clinical evaluation alone does not ensure each learner experiences the opportunity to interpret the types of tracings necessary to confirm interpretation competence.

Lastly, intra- and interrater consistencies of EFM interpretations are a known concern (Ranum et al., 2015; The Joint Commission, 2004). Yet, no studies analyzed in this review included evaluation of intrarater consistency and only Govindappagari et al. (2016) addressed interrater consistency. Still, that study failed to positively address consistencies in interpretations related to decelerations, a crucial component of determining clinical interventions in preventing adverse outcomes. Also, the researchers only looked at the correlations of interpretations of EFM tracings documented by nurses and physicians and did not determine the accuracy of these interpretations compared with actual chart tracings. Thus, the singular study addressing this crucial issue failed to confirm or fully support improvements in interrater interpretation consistencies.

Conclusion

The findings of this review provide evidence of the need for improved processes for training and evaluating competence in interpretation of EFM tracings. In reimagining current processes, adopting methods that integrate best practices of motivational and workplace learning in the design of educational interventions is warranted. Additionally, for the education to be most effective, it is best to individualize learning, provide opportunities for expert-facilitated deliberate practice, and include accurate measurement of competence. Realistically mimicking the interpretation of EFM tracings by integrating live-feed tracings also is essential to promote learning transfer to clinical practice and improve intra- and interrater consistencies in interpretations of EFM tracings among multi-disciplinary teams.

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CHAPTER III
CONCEPT ANALYSIS

Nurse Competence in Diagnostic Health Care Technologies:

A Concept Analysis to Inform Clinical Education

This article has not been published, nor will it be before I submit the final version into the Tennessee Research and Creative Exchange (TRACE). The manuscript is currently formatted according to author guidelines for submission to the *Journal of Clinical Nursing.*

I initially authored this manuscript as an end-of-course paper in my nursing research and inquiry course (NURS 603). In this course, I received guidance on the content development from Dr. Mary Gunther and Dr. Samereh Abdoli. Dr. Joel Anderson, my dissertation chair, shared additional feedback and editing for the final draft.

Abstract

Aims: This analysis aims to conceptualize nurse competence in diagnostic technologies by revealing the complexities of the implementation and use of these technologies to enhance patient outcomes.

Design: Rodger's Evolutionary Method guided the concept analysis.

Data Sources: A literature search was carried out in October 2019 including key terms and Boolean building blocks using PubMed and the Cumulative Index of Nursing and Allied Health Literature (CINAHL).

Review Methods: Inclusion criteria comprised articles published in English between January 2009 to October 2019 in peer-reviewed journals that were relevant to inform the international nursing concept of nurse competence in diagnostic technologies. Five publications were identified following the literature search. The analysis included examination of surrogate terms, related concepts, attributes, antecedents, and consequences.

Results: Surrogate terms interchangeably aligning with the concept included nurse technological competence and competency verification, and related concepts encompassed competence in two specific diagnostic technologies. Discovered attributes to nurse diagnostic technology competence were engagement with the patient and machine, capable users, meaningful skills, and overall positive attitudes. Antecedents coinciding with the concept were enthusiastic attitudes towards technology and integration methods of the technologies. The resulting consequences were improved patient outcomes, team communication, and caring nurse practices.

Conclusions: The discoveries identified during this analysis found existing practices for implementation and use of diagnostic technologies do not support nurse competence, which, in turn, lead to inadequate team communication and adverse patient outcomes when technologies are used.

Impact: Nurse competence in using diagnostic technologies as a well-defined concept is lacking. This concept analysis highlights two primary needs: for nurse leaders to ensure essential nurse competencies include diagnostic health care technologies and for future research related to these competencies.

Keywords: Nurse competence, diagnostic health care technology(ies), concept analysis, Rodgers' Evolutionary Method

Nurse Competence in Diagnostic Healthcare Technologies:

A Concept Analysis to Inform Clinical Education

Nurses enter patient rooms 45% more often than other health care personnel (Cohen et al., 2012). To provide safe care, they must possess competence in a wide array of essential skills. Meretoja et al. (2004) defined seven categories of nurse competence: (a) helping role, (b) teaching-coaching, (c) diagnostic functions, (d) managing situations, (c) therapeutic interventions, (f) ensuring quality, and (g) work role. This paper focuses specifically on nurse competence in diagnostic technologies aligning with two categories defined by Meretoja et al., diagnostic functions and managing situations. Nurse competence in using health care technologies leads to improved patient outcomes and caring practices (Pepito et al., 2019; Sipe et al., 2003). However, a definition of nurse competence specific to the use of diagnostic technologies does not exist. Thus, this concept analysis aims to establish a foundation for the concept of nurse competence in in the use of diagnostic technologies by revealing the complexities in implementing and using processes to promote enhanced patient outcomes when integrating diagnostic technologies into care.

Background

As the development and implementation of diagnostic health care technologies continue to expand, nurses possessing competence in using these technologies are essential to provide safe care. Diagnostic functions, as defined by the National Academies of Science, Engineering, and Medicine (2015), are responsibilities in the nursing diagnosis process described as “a complex, patient-centered, collaborative activity that involves information gathering and clinical reasoning to determine a patient’s health problem” (p. 218). Multiple health information technologies and tools are engaged in the diagnostic process to manage clinical situations (Balogh et al., 2015).

However, improved patient outcomes are not guaranteed when incorporating new technologies, as misuse leads to health care errors (Simpson et al. 2016; Kuhn et al. 2015; Sittig & Singh, 2011; Rautaharju et al., 2012; The Joint Commission, 2013).

Improved patient outcomes are possible when data from diagnostic technologies encourage prompt recognition, accurate interpretation, and appropriate intervention (Holmboe & Durning, 2014). However, diagnostic technologies fail to improve patient outcomes when competence is not secured (The Joint Commission, 2004; Rautaharju et al., 2009; Taner et al., 2012). Furthermore, care provided using technology is often viewed as disruptive considering the value placed on the caring nature of nursing practice (Locsin & Ito, 2018).

Understanding the separate definitions of diagnostic technologies and nursing competence is paramount before analyzing the concept of nurse competence in diagnostic technologies. Health information technology (Health I.T.) tools, identified by the National Academies of Sciences, Engineering, and Medicine (2015), are a range of technologies adopted for electronic medical records, clinical diagnostics, patient engagement, and medical devices. Health I.T. tools are used to capture patient physiologic information, shape workflow, inform clinical decisions, and exchange patient data (The National Academies of Sciences, Engineering, and Medicine, 2015). Thus, the definition of a diagnostic health care technology is a device used to capture and relay necessary diagnostic patient data informing clinical care decisions.

Merriam-Webster (competence, 2019) defines competence as “the quality or state of having sufficient knowledge, judgment, skill, or strength (as for a particular duty or in a particular respect)” (para. 1). However, defining competence within health care is daunting. The definition above implies having competence necessitates not only possessing cognitive knowledge to perform a task, but also suggests one must hold the psychomotor ability to carry out a skill safely. Unfortunately, defined competence related to diagnostic health care technologies is scarce despite the wide adoption of current technologies and rapid growth of new technologies.

Methods

Search Method

A university librarian with content expertise in nursing and library science and the primary author gathered the data for this analysis by engaging identified search threads and the key search words and terms: “nurse,” “competence,” and “technology(ies)” or “diagnostic function technology(ies).” Key term manipulation occurred by forming Boolean building blocks entered in PubMed and the Cumulative Index of Nursing and Allied Health Literature (CINAHL) databases.

The search occurred in October of 2019 and was limited to publications between January 2009 to October 2019. Inclusion criteria comprised peer-reviewed publications in English from sources relevant to nurse competence in using diagnostic technologies. No exclusion criteria were identified. An integrative review initiated by the first author of this article evaluated relevant sources, and the process was documented using a flowchart based on the Preferred Reporting Items for Systematic reviews and Meta-Analysis (PRISMA) (Moher et al., 2009) (see Figure II.1).

Search Outcome

Initial searches produced 924 publications from CINAHL and 808 from PubMed; eight additional articles were identified during the manual investigation. Following the removal of duplicate publications, 116 remained. Further review removed 89 reports, leaving 27 publications for screening to ensure alignment with the aim of the concept analysis. Following this process, only five publications were deemed relevant (see Table III.1).

Quality Appraisal

Rodgers' Evolutionary Method for concept analysis guided the inquiry (Rodgers, 2000). This method was ideal as it concedes differences in contextual use, offers perspectives from the view of other disciplines, and includes the opportunity for concept evolvement throughout the analysis (Rodgers, 2000). Using an evolving method was particularly attractive to develop the concept further as it coincides with the changing landscape of diagnostic health care technologies.

Data Abstraction

Thematic analysis of surrogate terms, related concepts, attributes, antecedents, and consequences was conducted. Surrogate terms were used interchangeably with the concept to convey similar ideas expressed using different terminology. Related concepts enhanced the analysis by revealing other concepts showing resemblance but not sharing the same characteristics or attributes. Identifying attributes provided insight to determine common uses with specific traits defining the concept and allowing for easier concept recognition and occurrence (Rodgers, 1989). The antecedents also uncovered revelations leading up to the concept. Finally, repeated consequences confirmed the concept had materialized, as evidenced in the literature.

Discovering how competence in using diagnostic technology affects care provided clarification to consider its uniqueness specific to nursing applications. As new technologies surface, care is disrupted rather than enhanced if these are not implemented thoroughly. Rodgers'

Evolutionary Method encouraged conceptual clarification and established a foundation for additional heuristic inquiry (Rodgers, 2000) to appropriately inform the nursing discipline.

Results

Surrogate Terms

Surrogate terms allow interchangeable use, or in a similar context, to the concept of analysis (Rodgers, 2000). Nurse competence in using diagnostic technology as a concept did not exist in the literature, but several instances of terms adopted for similar purposes such as technological competence, complex medical technology competence, and competency verification were found (See Table 2). Konguswan and Locsin (2011) conceived the term *technological competence* as the "ability of the nurse to use caring practices to know the nursed more fully" and to use technology to "get patients to be partners in their care (pg. 108)." Technological competence aligns with nurse competence in using diagnostic technologies by promoting understanding nurses "know the nursed" by using diagnostic technological skills to inform care. Competence in using complex medical technology and verification of that competency are terms that reference competence in diagnostic health care technologies, such as defibrillators used to produce cardiac tracings and deliver an electrical shock to treat cardiac arrhythmias (Phillips, 2019). See Table III.2 for a summary of surrogate terms and related concepts.

Related Concepts

Related concepts are similar to the analysis concept but acquire slightly different traits or qualities (Rodgers, 2000). Related concepts aligning with nurse competence in using diagnostic technologies outlined in Table IV are competence in using Ventricular Assistive Devices (VAD) (Casida et al., 2018) and birth technology (Crozier, Sinclair, Kernohan, & Porter, 2006). These related terms referenced nurse competence in using specific diagnostic devices. Casida et al. (2018) describe *VAD competence* as "having both technical and clinical knowledge for the VADs used in an institution as well as patient/caregiver self-care education (pg. 39)." The researchers found that VAD competence required more than just knowledge of the device, including communication skills and integrating the technology in a scaffolded manner (Casida et al., 2018). Crozier et al. (2006) defined three categories of birth technology competence specific to midwives: (1) knowledge of the machine and the pathophysiological processes of the mother in labor; (2) the ability to interpret, communicate, and use the machinery appropriately; and (3) demonstration of caring practices using a sensitive approach to respect the woman in labor (Crozier et al., 2006).

Attributes

Attributes are groupings of identifiable situations recognized as classifying a concept (Rogers, 2000). Four vital and contributing attributes of nurse competence in using diagnostic technologies were identified (see Table V). The most prominent attribute was a nurse's commitment to engage simultaneously with the patient and the machine (Casida et al., 2018; Crozier et al., 2006; da Silva & Ferreira, 2011; Konguswan & Locsin, 2011). Additional attributing circumstances were capable users (Casida et al., 2018; Crozier et al., 2006; Phillips, 2019), possession of meaningful skills (Casida et al., 2018; da Silva & Ferriera, 2011), and positive attitudes towards the technology (Casida et al., 2018; Konguswan & Locsin, 2011). See Table III.3 for the concept key and contributing attributes.

Commitment to Engage with Patient and Machine

Nurses committing to engage with the patient and the machine was commonly cited (Casida et al., 2018; Crozier et al., 2006; da Silva & Ferreira, 2011; Konguswan & Locsin, 2011). Engaging with the patient and machine was displayed by securing diagnostic technology competence and integrating technology as an expression of caring. In addition, nurses established caring practices with diagnostic technologies by integrating patient preferences (Konguswan & Locsin, 2011; Crozier et al., 2006), ensuring privacy, and communicating concerning technological data generated from the diagnostic technology to guide team-based care such as abnormal electrocardiogram tracings (da Silva & Ferreira, 2011; Konguswan & Locsin, 2011; Crozier et al., 2006).

Capable Users

Capable users are essential to ensure competent use of diagnostic technology (Casida et al., 2018; Crozier et al., 2006; Phillips, 2019). In addition, capable users possess ample technical and clinical knowledge (Casida et al., 2018; Phillips, 2019), adequate clinical experience (Casida et al., 2018), machine knowledge (Crozier et al., 2006; Konguswan & Locsin, 2011; Phillips, 2019; da Silva & Ferreira, 2011), the ability to perform clinical interventions (Crozier et al., 2006; Phillips, 2019), excellent communication skills (Crozier et al., 2006; da Silva & Ferreira, 2011), and a commitment to sustained competence (Casida et al., 2018).

Meaningful Skills

Nurses possessing competence in health care technologies were found to have meaningful skills including the skill of being very observant, recognizing data quickly, and the ability to experience a professional connection with the machine (da Silva & Ferreira, 2011; Crozier et al., 2006).

Positive Attitudes

Positive attitudes were present when nurses held readiness to integrate the technology, attained required technical competence (Casida et al., 2018), and initiated caring mannerisms in using the technology (Konguswan & Locsin, 2011). Nurses with positive attitudes took the initiative to learn and integrate the technology, which was crucial to safe use.

Antecedents

Antecedents precede the concept and are essential to the subsequent occurrence (Rodgers, 2000). In this analysis, nurse competence in using diagnostic technology did not present explicitly in the literature. However, the generalized concept of competence in using health care technologies existed and antecedents related to the necessary practices required for technology implementation, including implementation practices in the form of technology diffusion and education (Casida et al., 2018), and promoting enthusiastic attitudes (Konguswan & Locsin, 2011; Casida et al., 2018; Phillips, 2019; da Silva & Ferreira, 2011) (see supplemental material Table 6.1). See Table III.4 for the concept antecedents.

Implementation Practices

Formal implementation practices to diffuse new technologies into care promote nurse competence (Casida et al., 2018; Phillips, 2019) through acquisition of adequate technical and clinical knowledge of the innovation before application to care. Casida et al. (2018) determined technology adoption processes are essential when integrating a VAD. Adoption processes engaged nurse awareness of the technology and influenced successful use of the technology. Formal methods to onboard diagnostic technologies also influenced safe use technology and confirmed continued use during care delivery.

Intentional adoption of adult learning principles also was crucial when integrating health care technologies. Phillips (2019) described essential measures comprise: (1) a readiness assessment, (2) specific educational strategies, and (3) competency assessments. When integration processes are deficient or nonexistent, failure to ensure nurse competence potentially leads to patient harm.

Promoting Enthusiastic Attitudes

Konguswan and Locsin (2011) discovered overcoming nurse insecurities during integration of technology was essential to ensure attitudes towards the technology were enthusiastic and that nurses engaged adequately to acquire competence in using it. Da Silva and Ferreira (2011) also identified the personal characteristics of nurses to be excited and enjoy the acuteness of the environment where technology implementation occurred. However, promoting nurses' enthusiastic attitudes preceding technology integration and the unique characteristics inherent to deter technology adoption are often unknown until tepidness during integration is present.

Consequences

Rodgers (1989) defined a consequence as an event that follows concept formation, offering further conceptual clarification. During this analysis, significant consequences of nurse competence in using diagnostic technologies were identified: improved nurse competence, improved team communication, and promotion of caring practices when using technologies (see Table III.5).

Improved Nurse Competence

Casida et al. (2018) reported that nurses caring for a VAD patient possessed higher knowledge, adoption, and communication levels. Konguswan and Locsin (2011) described how nurses who attained diagnostic technology competence could care for patients holistically by adopting the technology into caring practices. Additionally, nurses lacking technology competence felt their diminished knowledge adversely affected care because unfamiliarity with the technology inhibited an ideal patient connection.

Improved Team Communication

Crozier et al. (2006) and da Silva and Ferreira (2011) described how nurse competence using diagnostic technologies in obstetric and intensive care settings also promoted improved team communication because the additional physiological data enhanced the information shared during communication. However, da Silva and Ferreira (2011) expressed difficulty in determining if improved team communication resulted from nurses' improved technology competence or established communicative characteristics. Crozer et al. (2006) identified nurse competence in the use of diagnostic technology, specifically electronic fetal monitoring, supported collaborative team communicative relationships between caregivers, the mother, and the technology.

Caring Practices

Konguswan and Locsin (2011) reported nurses obtaining competence in diagnostic technologies such as defibrillators felt this competence enhanced their caring practices. DaSilva and Ferreira (2011) further clarified an essential nurse having characteristics and techniques necessary for integrating technology into care. This figure-type nurse possesses the qualities to be proactive with emotional balance, strong communication and relationship skills, and critical nursing techniques including observation, leadership, expressive skills, speed, and dynamism.

Discussion

Before this analysis, a conceptual definition of nurse competence in using diagnostic technologies was absent in the literature. Diagnostic technologies integrated into patient care first emerged in the 1960s (Chen et al., 2018), and contemporary nursing care is provided chiefly with support from continually emerging diagnostic technologies. Yet, processes to assure nurses possess competence when using technologies are disappointingly lacking. Thus, a limitation of this analysis was the narrow scope of literature to define the concept.

Multiple facets of nurse competence in using diagnostic technologies are highlighted (see Figure 3.1), which are essential and vital attributes revealing the basic nurse characteristics for nurse administrators and educators to look for in nurses when onboarding diagnostic technologies. Additionally, screenings or evaluations to determine whether nurses possess the meaningful skills identified for competent use of health care technologies is essential. The features hiring nurse leaders should determine is whether or not a nurse has an attitude to learn the essential technologies to provide safe care, observant enough to recognize concerning diagnostic technology data quickly, possess competence to understand and troubleshoot technologies, and synthesize care to integrate the technology with a commitment to both the patient and the machine. Integration of diagnostic technologies must include intentional education and evaluation measures to determine nurse competence reflected through safe use, caring practices, and reliance on the technology to inform crucial patient data, promoting enhanced communication with the health care team.

To promote the safe use of diagnostic technologies, nursing leaders must adopt purposeful integration measures. Ideal measures include using the recommendations revealed in the antecedent section of this analysis to initiate a formal adoption plan for technology integration. In addition, a commitment to evaluate nurse diagnostic technology competence must occur similarly to those ensuring nurse competencies for other essential skills. Thus, the definition of nurse competence in using diagnostic technologies developed through this analysis is the nurse's ability to integrate diagnostic technologies safely by possessing a commitment to engage simultaneously with both the technology and the patient, prompting adequate communication of the patient physiological status to the health care team in a quick, reliable, and accurate manner.

Conclusion

Possessing adequate nursing competence to provide safe patient care is essential. However, the vital skills in nursing constantly change and evolve with the continued development of new health care technologies. Nurses must commit to lifelong learning to keep up with evidence-based practices and newly developed health care technologies, including those used for diagnostic purposes. Having competence in diagnostic technologies is essential, as nurses rarely encounter patient care without health care technologies. Most publications discussing health care technologies address health information technologies. However, including diagnostic technologies in nurse education and competence evaluation is critical to encourage safe monitoring and assessment of the patient's physiological status.

Display of nurse competence in using diagnostic technologies must occur similarly to the vast array of patient care treatments and essential skills performed in nurse competence evaluations. Casida et al. (2018) offer solutions to promote nurse competence in using diagnostic technologies. These solutions suggest incorporating the adoption of technology by using well-planned education and integration. However, as noted by da Silva and Ferreira (2011), this alone is not enough to ensure the safe use of health care technologies. Nurses must also engage with technologies in an observant, fast, and dynamic manner. Furthermore, considering nurses must possess contextual skills specific to some health care environments, multiple diagnostic technologies are not suited for all nurses. Accordingly, careful contemplation regarding the ability and effectiveness of nurses to provide high-technology care should be acknowledged when hiring in acute care settings where technology is ubiquitous.

Using diagnostic technology as a vital tool for communication within the health care team also is a crucial aspect of nurse competence (Crozier et al., 2006; da Silva & Ferreira, 2011). Da Silva and Ferreira (2011) describe required nurse communication skills when using the technology not only as a means to communicate with team members, but also suggest nurses must be able to “understand the language of the machine” (pg. 620). The language of diagnostic technology requires precise interpretation. Thus, nurses employed on units with high numbers of diagnostic technologies must understand competence in these technologies is mandatory and warrants consideration when seeking acute care positions.

Konguswan and Locsin (2011) present nurse competence in diagnostic technologies as holistic with an “intentional and authentic presence of the nurse using technology as a caring person to know the nursed more fully.” Nurses’ competence in using diagnostic technologies is “knowing persons, through life-sustaining technologies, as a whole. Therefore, they become participants in their care rather than as objects of the nurse’s care” (pg. 108).

When integrating new technologies, clinical leaders tasked with confirming nurses’ competence in using diagnostic health care technologies must consider the essential elements identified in this concept analysis. Additionally, onboarding processes must rely not only on standard practices of the past but also on technology vendors to provide training. Using adoption stages to onboard diagnostic health care technologies is ideal. Additional competence promotion via peer shadowing and simulation experiences also encourages competence to be attained (Casida et al., 2018). The lack of literature available for the analysis reveals additional research on nurse competence in using diagnostic health care technologies is needed.

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CHAPTER IV
FINDINGS

A Randomized Controlled Trial Engaging a Simulation-Based Mastery Learning Approach to Address Competence in Interpretation of Electronic Fetal Monitoring Tracings

This article has not been published, nor will it be before I submit the final version into the Tennessee Research and Creative Exchange (TRACE). Thus, a publication statement is not included.

The article is written in AMA formatting for future submission to *Simulation in Healthcare*, the sole journal of the international and interprofessional Society for Simulation in Healthcare. I, Susan H. Hébert, was the primary researcher on the described study. I received direct guidance and editing feedback from my dissertation committee members; thus, they are listed as co-authors on the manuscript. Committee members contributing to this publication are Dr. Joel Anderson, my committee chair, and supporting committee members Dr. Tami Wyatt, Dr. Suzan Kardong-Edgren, and Dr. Cathy Hammons. Gregory Gilbert, a consulting statistician, oversaw the statistical analyses of the data and results reporting. Robin Swaggerty, a nurse educator from the University of Tennessee, Medical Center in Knoxville, Tennessee, delivered the deliberate practice intervention, and also reviewed the final manuscript.

Abstract

Introduction: Global rates of neonatal deaths remain at 17 per 1000 births and researchers found this is partly due to inaccuracies and inconsistencies in the interpretation of electronic fetal monitoring (EFM) tracings and the quality of training and evaluations to confirm competence in interpretation of EFM tracings. **Methods:** The study, a randomized longitudinal design, included interprofessional participants from one hospital in the southeastern United States. Researchers compared participant's demographic characteristics to baseline scores using an EFM competence measurement tool followed by the intervention, a Simulation Based Mastery Learning (SBML) approach. The intervention included deliberate practice (DP) feedback from an expert in EFM guided by baseline scores and provided simulated experiential learning using a digital application to mimic live-feed tracings. Two evaluations measured competence at one month and three months between the intervention and clinical experience alone. Analyses included evaluation data for 23 participants completing three outcome measures. **Results:** Medium effect associations were present between baseline competence scores and level of education (r=.36) and

EFM training ($r=.33$). Correlations between competence scores and clinical experience ($r=-.20$) and obstetric experience ($r=-.16$) showed a moderate inverse relationship. Univariate comparisons between groups across time showed significant results one month post-intervention ($p=.006$) but not at three months. Between group comparisons on accuracy of EFM criteria showed significance in correctness of interpretations evaluating marked fetal heartrate variability ($p=.016$; $p=.029$; $p=.024$) and Category III tracings ($p=.002$), and comparisons across the three times of evaluations were significant for FHR moderate variability ($p=.029$; $p=.044$), FHR minimal variability ($p=.004$), FHR marked variability ($p=.007$), FHR prolonged deceleration ($p=.004$), three Category II tracings ($p=.043$; $p=.043$; $p=.041$), and one Category III tracing ($p=.047$). The intervention group scored higher percentages of correct responses to interpretation of tracings for all criteria questions showing significance in both between group and time comparisons. **Conclusions:** Regardless of study limitations, the results provide critical insight into the feasibility of using a SBML with DP intervention as an approach to promote improved accuracies and consistencies in interpretation of EFM tracings.

Key Words: electronic fetal monitoring, Simulation Based Mastery Learning, interpretation, competence, deliberate feedback

A Randomized Controlled Trial of a Simulation-Based Mastery Learning Intervention to Address Competence in Interpretation of Electronic Fetal Monitoring Tracings

Electronic fetal monitors (EFM) prevent adverse neonatal outcomes; however, the anticipated larger scope of impact from integrating the technology on neonatal outcomes has yet to occur. In 2009, the lack of a standardized and universally accepted interpretation classification system prompted the governing bodies for obstetric care, including the American College of Obstetricians and Gynecologists (ACOG), the Society for Maternal-Fetal Medicine (SMFM), and the National Institute of Child Health and Human Development (NICHD), to establish a more defined system to interpret and categorize EFM tracings[1]. Nonetheless, improvements in neonatal outcomes did not transpire and neonatal mortality rates remain unsettling worldwide. The latest global rates of neonatal deaths are 17 per 1000 births[2], and research over the last decade reveals this is partly due to inaccuracies and inconsistencies in the interpretation of EFM tracings[3,4,5]. Inaccurate interpretations are concerning considering responsive and collaborative intrapartum team care depends on accurate interpretations of EFM tracings[6,7].

A credentialing exam developed by the Perinatal Quality Foundation exists for nurses and physicians with the purpose of confirming competence in interpretation of EFM tracings[8], although standardized policies on how to maintain competence among obstetric professionals following the credentialing exam do not exist. This failure to ensure competence in interpretation of EFM tracings is unacceptable given the potential consequences of errors on neonatal outcomes[9]. For example, in a study by Hruban et al.[3], a retrospective comparison of physicians' interpretations of EFM tracings with umbilical artery pH, base deficit, and five-minute Apgar scores after birth found direct correlations between poor neonatal outcomes and errors in interpretations of EFM tracings. Researchers also correlated interpretation errors with the quality of training and evaluations to confirm competence in interpretation of EFM tracings[10, 6, 11, 12].

Thus, this study addresses the primary issue of ensuring competence in interpretation of EFM tracings by (1) identifying individual strengths and weaknesses in a health care provider's competence; (2) providing focused, expert-facilitated remediation guided by the identified weaknesses; and (3) assessing the provider's competence in interpretation of EFM tracings using an evidence-based evaluation tool. This innovative training method, called simulation-based mastery learning (SBML)[13], is recommended when 100% competence of a skill supports improvements in clinical care and patient outcomes. In addition, the SBML modality is proven to promote transfer of learned behaviors for enhanced clinical practice and improved patient outcomes[14,15.] The SBML method includes deliberate practice (DP)[13]. Deliberate practice is purposeful practice guided by identified outcomes and expert facilitators through individualized instruction directed by the learning needs of each participant[16]. Unique features of DP include motivated learners, specifically defined performance measurements, feedback at an appropriate level for the learner, repetitive practice, self-monitoring, and communication from learner to share readiness for final evaluations[13].

Three complementary psychological foundations ground the SBML model: behavioral, constructivist, and social cognitive[13,14]. All three theories frame learning focused on professional development in the context of workplace learning. The behavioral framework influences the learning by focusing on changing behaviors and improving outcomes identified, defined, and measured at baseline[13, 17]. The constructivist influence supports active learning and constructs meaning by surrounding the learning needs of individuals through social activity[18]. The social cognitive theory assumes learning occurs because of interactions between the self, behavior, and the environment; motivated social processes that influence learning and performance; and enactive and derived learning[19].

Many have used SBML with great success to train and evaluate learning outcomes for a diverse array of clinical skills. However, no other investigators have used a SBML method to train obstetric personnel on the skill of interpreting EFM tracings. In light of this knowledge gap, this study assessed if relationships existed between demographic characteristics of the interpreters of EFM tracings and the level of competence in interpretation of EFM tracings, as well as the feasibility and efficacy of a SBML intervention to train and evaluate competence in interpretations of EFM tracings. We hypothesized that the SBML method would be a feasible and effective approach to train and assess competence in clarification of EFM tracings and improve participants' self-efficacy in interpreting tracings from EFMs compared with clinical experience alone.

Methods

Study Site and Participants

A convenience sample from the labor and delivery and antepartum units of an academic teaching hospital in the southeastern United States was used. Before initiation of any study procedures the IRB approved the investigation. The inclusion criteria recruited hospital personnel who were registered nurses, nurse midwives, obstetric physicians, or resident physicians with a practice contract or current employment in the labor and delivery or antepartum units and work responsibilities that included interpretation of EFM tracings. The exclusion criteria eliminated obstetric personnel in these units who were on leave for six or more weeks at the beginning of the intervention period.

Study Procedure

The study used a randomized longitudinal design. Recruitment occurred using posters and face-to-face presentations in the labor and delivery and antepartum units. Participants confirmed consent via an online survey shared during recruitment meetings or using a QR code on recruitment posters. After obtaining consent, the primary investigator randomized participants into either the intervention or control group using a four-block, masked allocation scheme. After baseline evaluations, the intervention group received the SBML with DP educational training. The control group received no additional training beyond their individual clinical experience.

Assessment of outcomes occurred at three time points for both groups. First, all participants completed a baseline evaluation of their competence in interpretation of EFM tracings (described below). This evaluation coincided with the inception of the study period and participants received encouragement via email to complete the pre-intervention evaluation within 48 hours of consent. If participants did not complete the pre-intervention survey within this timeframe, the primary investigator sent a reminder email to encourage completion within a second 48-hour timeframe. The researcher excluded all participants not completing the entire investigation.

Initial post-intervention evaluation occurred two to four weeks following the baseline measurement. The intervention group completed an initial post-intervention evaluation within 48 hours after completing the intervention, while the control group completed the post-intervention evaluation within two weeks of their baseline evaluation. The researcher scheduled the intervention group for a SBML with DP training within two weeks of completing the baseline competence measurement on a date and time when participants were not scheduled to work.

Both groups completed a third competence evaluation three months after the initial post-intervention evaluation to assess efficacy of the intervention over time[20].

EFM-SBML with Deliberate Practice Intervention

An expert in interpretation of EFM tracings from the academic teaching hospital and trained by the primary investigator on the SBML with DP teaching technique carried out the intervention. The primary investigator scheduled intervention group participants for a one-hour DP session with the facilitator in small groups of three to four participants. To promote consistency and provide the low expert-to-learner ratio recommended for SBML, one DP facilitator delivered all the instructional intervention sessions[13].

The SBML with DP sessions included reflective teaching between the facilitator and participants guided by missed concepts on each individual participant's baseline competence evaluations. Concepts included identifying baseline fetal heart rate (FHR), variability in the heart rate, presence or absence of FHR accelerations and decelerations, and tracing categorization. In addition, group learning provided the opportunity to learn from the facilitator and engage in social interactions to observe other participants during the learning process and construct knowledge based on one's own and others' performance. Due to a crucial concern of study participant confidentiality, each session began with a pre-briefing to remind participants of the importance of confidentiality.

The SBML with DP intervention also included operationalizing the previously developed application for training and evaluating competence in interpretation of EFM tracings, the Simulated Electronic Fetal Monitoring (SEFM) app[21]. The SEFM app enhanced the facilitator's intervention training by using accurate representations of EFM tracings for training, practicing, and formative evaluation of interpretation during the SBML with DP sessions. During the SBML with DP sessions, the expert facilitator also referred to the recently published evidence-based EFM textbook by the Association of Women's Health, Obstetric, and Neonatal Nursing[22].

Measurement

The investigator judged competence of interpretation of EFM tracings using the EFM-Competence Evaluation Tool (EFM-CET). A collaborative academic and clinical team, including academic and clinical nurse and physician EFM experts, developed the EFM-CET as an online measurement to evaluate competence in interpretation of EFM tracings. The EFM-CET integrates realistic live-feed tracings through MP4 files generated from the SEFM app. Including live-feed tracings allows realistic mimicking of EFM tracings like those in the clinical environment. This feature is unique to the EFM-CET, which does not exist in other measurements of EFM interpretation competence. The tool displayed overall excellence (.903) in reliability using intraclass correlation coefficient analysis during research on the tool with novice EFM users. The EFM-CET contains items requiring answers to five individual criteria or interpretation responses to 18 EFM live-feed tracings. The adopted interpretation criteria guiding the EFM-CET came from the classification system defined by the governing bodies for obstetric care[23,24] and include three Category I tracings, 11 Category II tracings, and four Category III tracings. The higher number of Category II tracings allows the primary focus of the EFM-CET to be on commonly misinterpreted tracings among obstetric team members. The EFM interpretation questions for each live-feed tracing require the user to answer the following five questions based on the critical components of EFM interpretation[24]: (1) identification of fetal heartbeat as normal, tachycardic, bradycardic, sinusoidal, or indeterminate; (2) identification of heart rate variability as absent, minimal, moderate, marked, or sinusoidal; (3) identification of accelerations as 10×10, 15×15, absent, or prolonged; 4) identification of decelerations as early, variable, late, prolonged, or not present; and 5) classification of the tracing by category. If a participant answers each question on the 18 tracings, they will respond to 90 questions in total. The investigator defined competence as accurate interpretation of EFM tracings confirmed by 100% performance using the EFM-CET.

Additional items added to the EFM-CET for this study gathered data on participants' demographic characteristics, self-efficacy, and attitudes regarding the feasibility of the intervention. The demographic items included the following: type of health care education completed, previous EFM training, EFM certification status, and years of clinical and obstetric experience. Because no tool exists to measure self-efficacy related to EFM interpretation, four questions adapted from the Healthcare Technology Self-Efficacy (HTSE) tool[26] measured participants' levels of self-efficacy in interpretation of EFM tracings at baseline and three months post-intervention. Each HTSE item seeks responses from health care technology users using a seven-point Likert scale: (1) strongly disagree, (2) disagree, (3) somewhat disagree, (4) neutral, (5) somewhat agree, (6) agree, and (7) strongly agree. The four items selected from the HTSE measured participants' levels of self-efficacy to interpret EFM tracings in terms of ease of interpretation, capability to interpret, comfort in interpreting, and worry about how incorrect interpretations could risk the prevention of adverse neonatal outcomes. Finally, two questions assessed study feasibility by gathering participants' attitudes towards the SBML with DP intervention at the three-month follow up using a five-point Likert scale: 1) extremely unlikely, 2) unlikely, 3) neutral, 4) likely, and 5) extremely likely. The feasibility questions prompted participants to rate willingness to engage in a future SBML with DP intervention for EFM interpretation and the degree the SBML with DP intervention influenced their level of competence to interpret EFM tracings.

Statistical Analyses

The statistician analyzed data using R v4.2.1 with an *a priori* alpha level set at α=.05. The researcher calculated sample size using G*Power 3.1[27]. Based on a power level of 0.8, a large effect size (0.4) with the correlation between repeated measures set at 0.3, and the nonsphericity correction at one using a repeated-measures ANOVA[28], maintaining a sample size of at least 16 participants in each group would provide sufficient power.

Welch's *t*-test[29] was used to assess univariate differences in quantitative participant characteristics; normality was assessed using the Anderson-Darling[30], Shapiro-Francia[31], and Shapiro-Wilk[32] tests with an alpha level of 0.15. Cramer's V[33] measured effect sizes for associations between nominal and quantitative variables with 0.1 representing a small effect size, 0.3 a medium effect size, and 0.5 a large effect size. Point biserial correlations[34] assessed associations between quantitative and nominal data.

A generalized linear mixed model (GLMM)[35] and likelihood ratio testing tested the null hypothesis of no treatment effect and no time effect for each EFM-CET question for all 17 tracings (i.e., 85 models). Repeated measures ANOVA[36] assessed overall scores. Due to the ordinal nature of the self-efficacy scores, the researcher rank-transformed scores and applied a linear mixed model along with likelihood ratio testing to test the null hypothesis of no difference between groups and no difference in time. Descriptive statistics described feasibility of the SBML model with DP training to promote competence in interpretation of EFM tracings.

Results

At study inception, the researcher randomized 68 participants into either a control (n=35) or intervention (n=33) group with 55 completing the baseline evaluation (control, $n=27$; intervention, n=28), 36 completing the initial post-intervention evaluation (control, n=18;

intervention, *n*=18), and 23 completing the final three-month post-intervention evaluation (control, *n*=11; intervention, *n*=12) (see Figure 1). However, for this study results are only reported on the 23 participants who completed all three outcome measures. When accessing the baseline EFM-CET survey delivered through Qualtrics, one Category II tracing did not display adequately. The IRB approved deletion of this question; thus, the final instrument consisted of 17 questions.

Association of Participant's Characteristics to Baseline Scores

As seen in Table 1, the associations between the control and intervention group characteristics did not reveal significant evidence of between group differences in education (p=1.000); type of previous EFM training (p=.833); EFM certification status (p=1.000); years of clinical experience (p=.368); years of obstetric experience (p=.469); or baseline competence scores (p=.252). Using Cramer's V to judge the associations between characteristics and baseline competence scores, baseline scores showed an association with level of education (r=.36) and EFM training (r=.33), a medium effect size. Certification status showed no association (r=.02). Point biserial correlations for clinical experience (r=-.20) and obstetric experience (r=-.16) showed a moderate inverse relationship with baseline competence scores.

EFM-CET Overall Score Comparisons

Univariate comparisons of EFM-CET scores between groups at over time showed significant results one month post-intervention (p=.006) with the intervention group participants mean score at the one month post-intervention evaluation at 80.2 (SD 3.13) and the mean score for control group at 73.6 (SD 6.12). Also, even though the differences between the intervention and control group scores at month three did not reflect a significant difference, the mean score for the intervention group was higher (77.1) than the control (73.8) (Table 2). Based on the repeated measures ANOVA, there is statistical evidence of a difference in pairwise competence score comparisons between baseline and one month post-intervention (*p*=.004), but not between baseline and three months post-intervention (*p*=.188) or the two post-intervention time points (*p*=.133) (Table 3). Scores of the control group did not change significantly over the three evaluations, while those of the intervention group did (Table 4), and the intervention group reflected higher mean scores at each of the two post-intervention measures (Table 2). Using a Bonferroni correction, there was again a significant difference in competence scores in the improved scores of the intervention group between baseline and one month post-intervention (*p*=.008) as compared with the other group-time specific comparisons (Table 5). A pairwise *t*-test of data, collapsing across times, showed a significant difference in scores between baseline and one month post-intervention (*p*=.011), but not between baseline and month 3 or comparisons for month 1 to month 3 (Table 6).

Accuracies of Interpretation EFM on Specific Tracing Criteria

Numerous criteria responses to the 17 interpretation questions could not be modeled due to participants from both groups scoring 100% accurate (Table 7). However, the analysis on the criteria questions still yielded valuable results. Significant differences displayed for multiple between group associations with the intervention group scoring significantly higher percentages of correctness in their interpretations on several questions related to FHR marked variability (Tracing 5, *p*=.016, RR=4.4; Tracing 7, *p*=.029; RR=15.4; Tracing 9, *p*=.024, RR=13.0) and one Category III classification (Tracing 15, *p*=.002, RR=71.4). For example, the relative risk showed us on Tracing 15 the intervention group was 71.4 times as likely to interpret the tracing accurately than their peers who did not receive the SBML with DP intervention. Also, see

Appendix IV.A for the percentages and frequencies of correct interpretation responses to each of the 17 tracing questions at each point in time.

Accuracy of Interpretation Tracing Criteria - Between Groups

Only four between-group comparisons of the 17 tracing interpretations showed significant differences in correctness of interpretations, with three of the four interpretations evaluating marked FHR variability of the Category II tracings [Table 2; Tracing 5 (p=.016); Tracing 7 (p=.029); and Tracing 9 (p=.024)]. The fourth criterion displaying of Tracing 15, a Category III tracing, demonstrated a significant improvement in correct classification (p=.002).

Data analysis (See Table 7) revealed multiple instances relating to each criterion of FHR tracings (Baseline FHR, Variability, Accelerations, Decelerations, and Category) where SBML with DP training improved accuracies of participants' interpretations. However, those showing more than double the likeliness to improve interpretation accuracy were related to interpretations of FHR variability and categorization. These results must be interpreted with caution due to the small sample size.

Accuracy of Interpretation Tracing Criteria - Between Repeated Measures

Comparing accuracy of interpretations between the groups at baseline, month 1, and month 3 also showed the intervention group scored significantly better in interpreting several criteria of the tracings over time (Table 7). Interpretation of FHR variability demonstrated significant improvement for the following tracing interpretations; Moderate [Tracing 2 (p=.029); Tracing 3 (p=.044)]; Minimal [Tracing 8 (p=.004)], and Marked [Tracing 9 (p=.007)]. One question evaluating identification of a FHR deceleration showed a significant difference in the three evaluations over time [Tracing 5 (p=.004)] with the intervention group having higher percentages of accuracies at baseline and month 3 and the control group scoring better at month

1. Also, four classification questions revealed a significant difference of interpretations between three repeated evaluations with the intervention group scoring better at all month 1 evaluations: Category I [Tracing 4 (p=.043)], Category II [Tracing 5 (p=.043); Tracing 12 (p=.041)], and Category III [Tracing 15 (p=.047)].

Between-time comparisons from baseline to month 1 found the intervention group participants more than twice as likely to be accurate in interpretations at month 1 compared with baseline (Table 7). These interpretations included sinusoidal FHR [Tracing 15 (RR=2.9)]; moderate FHR variability [Tracing 3 (RR=226.8)]; marked FHR variability [Tracing 5 (RR=4.3), Tracing 9 (RR=34.2)]; minimal FHR variability [Tracing 8 (RR=19498.0)]; prolonged FHR decelerations [Tracing 5 (RR=6211.3)]; Category II [Tracing 4 (RR=16283802.9); Tracing 5 (RR=10.5), Tracing 10 (RR=2.0), Tracing 12 (RR=406.4)]; and Category III [Tracing 15 (RR=4.4)]. Analysis of intervention participants' correct responses from baseline to month 3 also showed multiple criteria more likely to be correct at month 3.

Participant Ratings of Self-Efficacy and Intervention Feasibility

Between group comparisons of ratings of self-efficacy across the three time points in the study did not reveal any significant differences (Table 8). Of note, the response by those in the control group decreased from baseline (M=5; "somewhat agree") to month one (M=3; "somewhat disagree") for the question, "I worry I might interpret the tracing incorrectly and risk preventing adverse neonatal outcomes." Based on the five-point Likert scale, participants responded to "likely" for willingness to engage with the intervention (M=4.1), and "neutral" (M=3.4) to the degree they felt their self-efficacy scores influenced their competence in interpreting EFM tracings (Table 9).

Discussion

Even though the study did not sustain adequate participant numbers across longitudinal measures to retain statistical power, the evidence of significant improvements in scores on the EFM-CET in the intervention group over time demonstrated the SBML with DP intervention is efficacious in supporting improved accuracies in interpretations of EFM tracings. Furthermore, participants who received the SBML with DP intervention displayed improved accuracy in interpretations related to FHR variability and Category II tracings. The enhanced accuracy of interpretations for these types of tracings is an impactful finding considering Frey et al.[37] found the correct classification of Category II tracings has an overall positive predictive value for neonatal acidemia, a direct cause of encephalopathy in newborns following trauma experienced during the intrapartum period of birth.

Discoveries from this study showed participants' levels of competence in interpreting EFM tracings were inversely associated with years of clinical experience at baseline, indicating that previous training and more experience did not support sustained competence in interpreting EFM tracings. These findings contradict Benner's[38] commonly adopted *From Novice to Expert* nursing model of developed expertise, stating more clinical experience leads to higher levels of competence. However, the study results comparing participants' years of experience to baseline scores align with work by Ericsson and Pool[39], showing competence is not directly associated with extended time but attained through deliberate practice by motivated learners who receive individualized instruction guided by a content expert. Not surprisingly, comparisons of education and training to baseline evaluations reflected higher levels of education and more advanced EFM training were associated with higher baseline competence scores.

Previous research on the reliability of obstetric personnel interpretations of EFM tracings revealed poor clinical outcomes from a lack of intra- and inter-rater reliability in interpretations.[40,41] Because poor neonatal outcomes can result when errors of interpretation of EFM tracings occur, a 100% score on the EFM-CET defined competence for this study. Yet, because no participants met competence by scoring 100% on the EFM-CET, 100% accuracy may be an unrealistic expectation in interpreting EFM tracings. Findings from this study align with the most recent clinical research revealing the accuracies of interpretations of EFM tracings remains a concern. [43,44,45] Thus, competence in interpreting EFM tracings continues to warrant further research to improve accuracies and intra- and inter-rater reliability of interpretations. Future studies using the EFM-CET as an outcome measure may consider using the commonly used Mastery Angoff Method[42] approach to set a minimum passing standard for the EFM-CET tool. This standard-setting method is frequently used in education settings to identify realistic minimum passing scores in SBML research[13] and performance examinations in health professions education.

The lack of participants to reach 100% skill mastery also may be related to the group size (three to four participants to one DP facilitator) used in this study. A lower learner-to-expert ratio, such as 1:1 recommended for deliberate practice[46], may produce scores closer to 100% on the EFM-CET. Although, sustaining this level of individualized instruction would be costly and difficult to maintain in a clinical environment considering the expert time needed for each learner in a SBML with DP intervention. The lack of a significant association between levels of self-efficacy and participants' competence scores over time may also be reflective of the lack of participants to obtain a 100% competence score.

A minimal amount of research exists explicitly aimed at improving EFM interpretation. Most that exist focus on clinical decision-making in response to tracing interpretations, not the consistencies and accuracies in interpreting EFM tracings. The results of this study are similar to those of Cusanza et al.[47] (2020) and Govindappagari et al.[40] showing significantly improved outcomes following educational interventions. Cusanza et al.[47] included individualized e-learning modules aimed to improve interpretation. However, the outcome measure for the interpretation of EFM tracings did not evaluate the accuracies of interpretations but rather the participant's clinical response to the EFM tracings included in the evaluation tool. Govindappagari et al.[40] also reported improved interpretation consistencies following an e-learning intervention between physicians' and nurses' documentations of EFM interpretations regarding heart rate variability and accelerations upon admission. Nonetheless, they only measured intra- and inter-rater consistencies of interpretation of actual EFM tracings by reviewing intrapartum documentation on maternal charts and did not evaluate the accuracy of participants' interpretations.

Even though there are limitations to this current study, it still enhances the body of educational research initiated by Cusanza et al.[47] and Govindappagari et al.[40] aimed at improving interpretations of EFM tracings. The improved accuracies of interpretations of FHR variability by the intervention group are encouraging, considering FHR variability is one of the best indicators in EFM tracings of fetal distress[37]. However, in future research, participants must be required to repeat sessions with the DP facilitator until achieving a minimum passing score on the EFM-CET. Though it was not part of the research, following the study, all participants were offered additional DP sessions with the EFM expert and access to the SEFM application to promote improved scores on the EFM-CET.

One of the primary purposes of this study was to establish whether an SBML with DP intervention is a feasible method to train and evaluate competence in interpreting EFM tracings. Based on the participant's evaluated willingness to engage with the intervention and overall improved scores following the intervention, SBML with DP is a feasible training method to improve interpretations of EFM tracings.

The study revealed several research limitations. The required number of participants to support the *a priori* power analysis was not met due to an unanticipated decline in participant numbers over the three repeated measures. The researcher excluded all participants who failed to complete the EFM-CET evaluation survey within the predetermined timeframe or left employment at the study site before the study ended, affecting the overall sample size. In addition, the antepartum and labor and delivery units experienced nursing staff shortages, and deliveries increased by five percent in 2022 compared with 2021 during the study period. Also, even though it was encouraged, no participants took advantage of additional DP sessions with the EFM expert before taking the month one post-test. Subsequently, none displayed 100% accuracy on interpretations of EFM tracings following the DP intervention. In future studies, we recommend a quasi-experiment methodology without group randomization to exactly follow the SBML model.[13] Additionally, responsive DP sessions based on learner's needs must be a requirement if participants do not successfully attain the set mastery level on the first post-intervention evaluation similar to previous quasi-experimental studies whose SBML interventions resulted in all participants achieving skill mastery.[13,48,49,50]

Conclusion

Regardless of the study limitations, these results provide critical insight into the feasibility of using a SBML with DP intervention as an approach to promote improved accuracies and consistencies in interpretation of EFM tracings. The findings are especially encouraging considering the impact on improving accuracies for the most commonly misinterpreted category of tracings (i.e., Category II), which align with an increased potential for adverse neonatal outcomes if not accurately interpreted in a timely manner to prompt preventative care interventions in response to interpretation of EFM tracings.

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CHAPTER V – CONCLUSION

This chapter concludes the dissertation providing a synopsis of the study compared with the *a priori* research questions and aims. Limitations and recommendations for future research related to training and measuring competence in interpreting electronic fetal monitoring (EFM) tracings are discussed.

Previous experiences caring for infants with neonatal encephalopathy (NE), which sometimes occurs following a difficult birth, inspired this work. During problem discovery, a concerning issue with interpretations of EFM tracings included the inaccuracies and inconsistencies of interpretations (Santo et al., 2012; Sabiani et al., 2015; Clark et al., 2013; Nzelu et al., 2018). Further exploration into the literature found linkages between suboptimal (i.e., inaccurate and inconsistent) interpretations and insufficient training and competence evaluations to promote and sustain the skill of interpreting EFM tracings (Santo et al., 2012; Kelly et al., 2021; Sabiani et al., 2015).

Issues with training in and evaluations of interpretation of EFM tracings were delineated further by completing a scoping review of the literature on the current state of EFM interpretation education and assessment (Chapter Two). The literature review included publications related to training or evaluating EFM interpretation accuracy. Findings from the literature review established a need for further research on the processes of EFM interpretation training and evaluations to enhance the consistencies and accuracies of tracing interpretations. Specifically, future work in this area should include (1) multiple study settings and clinical environments to provide a global perspective; (2) a description of the educational modalities and methods used in curricular development; (3) inclusion of educational theories or frameworks used in the development of trainings; (4) a description of the specific EFM factors evaluated and the rigor of the evaluation measures used; (5) the inclusion of an operationalized definition of competence in interpretation of EFM tracings; and (6) the inclusion of intra- and/or interrater consistencies in interpretation.

The concept analysis (Chapter Three) of nurse competence in diagnostic technologies helped to provide a global understanding of the complexities of competence in interpreting EFM tracings. Rodger's Evolutionary Method guided the concept analysis. The inclusion criteria comprised articles published during the previous ten years from peer-reviewed journals relevant to the concept. The analysis identified five publications used to identify the surrogate terms, related concepts, attributes, antecedents, and consequences. Surrogate terms interchangeable with the concept were nurse technological competence and competency verification and related concepts encompassed competence in two specific diagnostic technologies: tracings from EFMs and electrocardiograms. Discovered attributes for using diagnostic technologies were engagement with the patient and machine, capability of users, meaningful skills, and positive attitudes. Antecedents coinciding with competence in diagnostic technologies were enthusiastic attitudes toward and integration of the technology. The consequences discovered in the analysis were improvements in patient outcomes, team communication, and caring nurse practices. The findings from the concept analysis provided information regarding existing methods for implementing and using diagnostic technologies, which, surprisingly, are not integrated into training or competence evaluations to use the technologies safely. This lack of regard for competency assessment can lead to inadequate team communication and adverse patient outcomes. The concept analysis concluded by highlighting two primary needs: to ensure instruction of diagnostic technologies to promote nurse competence and further research measuring competence to use diagnostic technologies safely.

To address the gaps identified through the literature review and concept analysis, the dissertation study was designed to assess whether relationships existed between demographic characteristics of the interpreters of EFM tracings and the level of competence in interpretation of EFM tracings, as well as the feasibility and efficacy of a simulation-based mastery learning (SBML) with deliberate practice (DP) intervention to train and evaluate competence in interpretations of EFM tracings. The study was designed to answer the following research questions:

Research Questions:

1. Do relationships exist between obstetric health care professionals' demographic characteristics, including (1) type of previously completed EFM training, (2) EFM certification status, (3) clinical role, (4) amount of clinical experience, and (5) amount of labor and delivery experience and competence in interpretation of EFM tracings?
2. What is the feasibility and efficacy of an innovative simulation educational intervention in educating, evaluating, improving intra- and interrater interpretation consistencies, and promoting sustained competence in interpreting EFM tracings?

From these questions, five research aims were developed as described below.

Research Aims

Aim 1: Evaluate the feasibility of participants to engage in a SBML with DP intervention in a clinical workplace setting.

Hypothesis 1: Participants will evaluate the SBML intervention as feasible for training, evaluating, and sustaining competence in interpreting tracings from EFMs.

Aim 2: Determine how obstetric nurses' and physicians' characteristics (differences in level and type of education, years of obstetric experience, years of clinical experience, previous training, and certification status) affect baseline scores of interpretations from EFMs.

Hypothesis 2: Participants with higher levels of education, more years of obstetric and clinical experience, and previous training and certification in EFM will demonstrate higher baseline competence scores.

Aim 3: Evaluate the effects of a SBML with DP intervention compared with clinical experience alone on competence scores and intra- and inter-rater consistency of interpretations of EFM tracings immediately following and three months post-intervention.

Hypothesis 3: Participants will display improved competence in interpretation of tracings from EFM following a SBML with DP intervention using the EFM-CET from pre- to post-intervention and sustain competence three months post-intervention compared with clinical experience alone.

Hypothesis 4: Participants receiving a SBML with DP intervention will be more accurate in their interpretations of categorizations (Category I, II, & III) of EFM tracings immediately following and three months post-intervention as measured using the EFM-CET compared with participants having clinical experience alone.

Aim 4: Evaluate the impact of a SBML with DP intervention on participants' levels of self-efficacy in the interpretation of tracings from EFM.

Hypothesis 5: Participants' levels of self-efficacy in competence in interpretation of tracings from EFM will improve following the intervention as measured using an adapted version of the Healthcare Technology Self-Efficacy (HTSE) tool (Rahman et al., 2016).

A randomized longitudinal design was operationalized to address the study aims. The study sample included interprofessional participants from a hospital in the southeastern United States. The study was based on an educational approach called Simulation-Based Mastery Learning (SBML) developed by McGaghie et al. (2020) at Northwestern University School of Medicine. The SBML method converges three educational theories; social cognitive, behavioral, and constructivist, which provided foundation and guidance of the curricular design. The study design supports motivated learners, formative evaluations of competence at baseline, an established process to guide the deliberate practice intervention, and summative evaluations intended to confirm skill mastery and downstream learning outcomes.

The baseline EFM competence measurement allowed for comparisons of participants' demographic characteristics with baseline competence scores. The researcher scheduled intervention group participants in small groups of three to four participants to receive an hour-long SBML with DP intervention. The researcher compiled the items answered incorrectly by participants in each SBML with DP intervention into concepts missed to share with the EFM expert who served as the DP facilitator. The DP facilitator used this information to guide the instruction for each small group. The SBML with DP intervention also integrated a digital application mimicking live-feed tracings called the Simulated Electronic Fetal Monitoring App. Two post-intervention measures followed completion of the intervention at one month and three months. Twenty-three participants completed the outcome measures at all three time points.

Participants responded with a rating of "likely" for willingness to engage with the intervention and neutral to whether the SBML with DP intervention impacted their interpretation scores using the EFM-CET. Therefore, hypothesis 1 was supported: a SBML with DP intervention is a feasible training method to improve interpretations of EFM tracings. Baseline competence scores were positive correlated with level of education (*r*=.36) and EFM training (*r*=.33), but inversely correlated with years of clinical (*r*=-.20) and obstetric experience (*r*=-.16). Thus, hypothesis 2 was not supported.

In terms of hypothesis 3, participants in the intervention group showed significant improvement in competence scores one month post-intervention (*p*=.008) but not three months. There was no difference in competence scores over time among participants in the control group. Thus, even though the SBML with DP intervention improved the intervention group's immediately following the intervention, these gains were not sustained over time. Between-group comparisons found increased accuracy in classifying the 17 tracings of the EFM-CET, particularly those related to fetal heart rate (FHR) variability and Category II tracings. These findings demonstrate the intervention positively impacted the accuracy of the participants' interpretations, supporting hypothesis 4.

Finally, there was no significant correlation between participants' levels of self-efficacy and competence scores over time. Self-efficacy within the SBML model is a product of mastery and measured by evaluating the learner's confidence to perform a pre-determined activity (McGaghie et al., 2020). Because improved S-E did not result in this study, hypothesis 5 is not supported. This finding may relate to the fact that no participants obtained 100% competence in interpreting the 17 EFM tracings, yet, potentially if learners acquired mastery or competence, their S-E could improve to reinforce and encourage sustained skill mastery over time. In future studies, additionally improved results may occur by planning a more individualized approach to the SBML with DP intervention. The individualized interpretation instruction can be delivered using remediation features already built into the SEFM app that shares just-in-time and evidenced-based feedback based on interpretation responses. Using the SEFM app rather than a DP facilitator additionally further standardizes the instruction and would be a more cost effective educational approach than requiring an expert facilitator to provide individualized instruction for a large clinical team.

Multiple limitations of this study warrant consideration when interpreting the results. Many participants did not complete evaluations at all three time points and participants with missing data were removed from the analysis, so, only 23 remained in the final analysis reducing statistical power and validity of the results. Also, the EFM-CET evaluation tool originally included 18 EFM live-feed tracings; however, because participants experienced technical difficulties with one tracing on the baseline evaluation, it required removing this tracing from the final two assessments. Traditionally, a SBML intervention does not require randomization into two groups, and all participants receive the SBML with DP training until mastery or reaching a minimum passing score. For this study, in addition to overall scores, the analysis included individual accuracies on each criterion of the 17 remaining tracings, requiring an adjusted SBML approach. However, following this study, participants were offered an additional opportunity for DP with the EFM expert to reach a higher competence score using the EFM-CET.

Additionally, because neonatal consequences of inaccurate EFM tracings are potentially severe, attaining competence for this study required 100% accuracy of interpretations. In retrospect, 100% accuracy may not be attainable on an EFM interpretation evaluation. However, the significance of improvement in the intervention group participant's EFM competence scores from baseline to post-intervention supports further study using a traditional quasi-experimental SBML approach.

Regardless of study outcomes showing no participants met the definition of EFM interpretation competence by scoring 100% on the EFM-CET, the results align with the most recent clinical research revealing the accuracies of interpretations of EFM tracings remains a concern. Nonetheless, findings of this pilot study showed a SBML with DP intervention did promote improved accuracies and consistencies in interpreting EFM tracings. Absent from the literature and this work is a clear definition of competence in interpretation of EFM tracings and after nearly 40 years of EFM use, the question remains why EFMs continue to be widely used especially considering the lack of resulting improvements in neonatal outcomes and difficulties in improving accuracies and consistencies of interpretations.

Future research to improve competence in the interpretation of EFM tracings must consider measuring accuracies for the criteria of EFM interpretation (baseline FHR, FHR variability, FHR accelerations, FHR decelerations, and categorization) and contemplate adding uterine activity to the evaluation. Studies integrating a SBML with DP approach to train and evaluate competence in interpreting EFM tracings should include a quasi-experimental SBML methodology without randomization to better support all participants reaching competence or mastery level of the interpretation skill and contemplate using the SEFM application until reaching a minimum passing score. Because no participants in this study achieved the defined skill competence, 100% on the EFM-CET, subsequent studies using the EFM-CET as an outcome measure should consider using the Mastery Angoff Method[42] approach to set a minimum passing standard for the EFM-CET tool. Additionally, future studies using a SBML with a DP approach must require participants to repeat DP sessions until achieving skill mastery.

APPENDICES

Table II.1

Publications included in the final literature review

Publication	Purpose	Setting/Participants	Theory	Defined EFM Competence	Sample/Design	Results
Carbonne, B. & Sabri-Kaci, I.	EFM knowledge evaluation	5 Maternity Departments of Eastern-Paris Perinatal Network (Midwives n=75/ Physicians n=38)	None	Not defined	Longitudinal experimental design with two randomized groups: 1) e-learning with training and 2) no training	Mean evaluation scores were significantly higher in the training versus no training group (p=.0026)—sustained competence between physicians and nurse midwives was statistically similar. In addition, participants who spent >4hrs on e-learning modules performed significantly better than those who spent <4 hrs. (p=.005).
Cusanza, S.A., Speroni, K.G., Curran, C.A., & Azizi, D.	Curriculum development for a perinatal safety training program (based on EFM) and evaluation of knowledge	Three hospitals in the southern United States Registered Nurses (n=55) 85.5% were nurses currently working in a clinical role,74.5% bachelor prepared, and 11.2 years of experience; competence assessments previous to this study: 41.8% national EFM certification and 58.2% trained through hospital-based or other methods.	Adult motivational learning	Remediation is assigned until a 100% score on the post-intervention survey is attained	Quasi-experimental design including outcomes from participant engagement in a 4-step e-learning intervention: step 1-baseline assessment, step 2-completion of individually identified modules based on the baseline, step 3-application of learning in the clinical environment, step 4-post-intervention evaluation. Post-intervention learning evaluation contained 39 questions, with seven questions requiring EFM interpretation. Each question was categorized into one of 5 areas of risk-management concern (cognition, communication, performance, professionalism, or system). Questions also ranked as high, moderate, or low risk related to the likeliness of causing patient harm if answered incorrectly.	Participants' overall learning scores significantly improved from pre- (76.7, SD=9.12) to post- (82.5, SD 6.9) intervention. In addition, a significant improvement from pre- to post-test was found for the concept of professionalism (p<.005), and question classifications by risk level also showed significant improvement (p<.008).

Table II.1, Continued

Publications included in the final literature review

Publication	Purpose	Setting/Participants	Theory	Defined EFM Competence	Sample/Design	Results
Govindappagari, S., Zaghi, S., Zannat, F., Reimers, L., Goffman, D., Kassel, I., & Bernstein, P.S.	Determine the effectiveness of a homegrown online EFM curriculum on intra-group reliability of interpretations	1 Hospital in New York Registered nurses (n=200) and physicians (n=228)	None	Not defined	Retrospective quasi-experimental design to retrospectively measure inter-group reliability of interpretations between nurses and physicians following an institutionally developed and mandated e-learning training	Found improved interpretation consistencies between physicians and nurses on EFM parameters of variability and accelerations at first tracing upon admission (variability: 91.1 vs. 98.3%, p<.0.001; and accelerations: 75.2 vs. 87.7%, p<0.001) and immediately prior to delivery (variability: 82.1 vs. 90.6%, p=0.001; accelerations: 56/7 vs/ 68.6%, p=0.0012). Improvements in the consistency of deceleration interpretations were not significant.
Jomeen, J., Jones, C., Martin, C.R., Ledger, S., Hindle, G., & Lambert, C.	Determine the immediate and sustained impact of childbirth emergencies in community (CEC) training on EFM interpretation	Community education in the United Kingdom Obstetricians=36, nurse-midwives=229, paramedics=28, students (midwives and paramedics=36), and unknown=15. Total participants (n=344)	None	Not defined	Longitudinal mixed-methods design. Pre- & post-measurement of EFM knowledge and confidence following an intervention, including a CTG face-to-face course and childbirth emergencies in the community (CEC) hands-on session facilitated by experts. The quantitative evaluation included knowledge questions but no direct CTG interpretation; meaningfulness, competence, impact, and choice. Qualitative measurement questions included feedback on attendee course expectations and how they applied to learn in clinical settings following training.	Empowerment and knowledge significantly improved for all groups following CTG and CEC training. In addition, CEC and CTG knowledge showed significant increases between pre- and post-training evaluations immediately (p<.001) and at three months (p<.001).
Keegan, R.D., Oliver, M.C., Stanfill, T.J., Stevens, K.V., Brown, G.R., Ebinger, M. & Gay, J.M.	Determine the effectiveness of a pre-class simulated learning exercise for EFM interpretation on learner EFM knowledge	Nursing program in the northwestern United States 116 undergraduate BSN students (n=32 intervention, n=84 control)	Just-in-time teaching (JiTT) pedagogy	Not defined	Experimental design comparing post-intervention knowledge on 10-item EFM content quiz of two groups. The intervention group experienced pre-learning activities on a simulated mobile EFM application versus the control (who were assigned traditional pre-learning methods of having pre-learning via assigned readings).	Students completing pre-quiz simulation mobile application intervention scored statistically higher (85%) on a post-intervention quiz than the control (70%) group (p=.01). Students perceived the simulated application as an engaging and desirable method to learn.

Table II.1, Continued

Publications included in the final literature review

Publication	Purpose	Setting/Participants	Theory	Defined EFM Competence	Sample/Design	Results
Thellesen, L, Sorensen, JL., Hedegaard, M., Rosthoej, S., Colov, N.P., Andersen, K.S., & Bergholt, T.	Determine the association between demographic characteristics of obstetric caregivers and EFM knowledge, interpretation, and decision-making	Included all (24) maternity units in Denmark Obstetricians (n=269), nurse midwives (n=1260), and residents (n=142)	Test development theory	Defined as having a score of 25 or higher on the 30-item evaluation.	A quasi-experimental cross-sectional study. Correlated participant demographic characteristics with post-test evaluations following an intervention comprised of an e-learning CTG program and a 1-day in-person CTG course. Learning outcomes were measured using a 30-item multiple-choice survey addressing fetal physiology, CTG interpretation and classification of a recorded strip, and clinical decision-making.	Participants working at hospitals with >3000 deliveries displayed significantly higher levels of CTG knowledge, accuracy in interpretations, & improved skills compared to those working at hospitals with <1000 deliveries/year (p=.006), and participants with < 15 years of work experience scored significantly higher than those with > 15 years work experience (p-.007), however, participants with 1-5 years, 5-10 years, and 10-15 years scores were not significantly different compared to those with <15 years of experience. In addition, work background showed no differences
Tomlinson, M.W., Brumbaugh, S.A., O'Keeffe, M., Berkowitz, R.L., D'Alton, M., & Nageotte, M.	Report on the effectiveness of the Perinatal Quality Foundation (PQF) EFM credentialing examination	Global audience All persons taking exam between Feb. 2014-Sept 2018 (n=2105 physicians/n=1756 nurses/ n=196 CNMs)	Script Concordance & Item Response Theories	Defined as at or above the set minimum passing score on PQF credentialing exam	Statistical reliability testing of EFM credentialling knowledge and clinical judgment measurement tool	PQF credentialing exam is a reliable, valid assessment of concepts of EFM competence and clinical judgment.

Table II.1, Continued

Publications included in the final literature review

Publication	Purpose	Setting/Participants	Theory	Defined EFM Competence	Sample/Design	Results
Wagner, B., Meirowitz, J., Shah, J., Nanda, D., Reggio, L., Cohen, P., Britt, K., Kaufman, L., Walia, R., Bacote, C., Lesser, M.L., Pekmezaris, R., Fleisher, A., & Abrams, K.J.	Reduce adverse obstetrical outcomes through a multi-step, multi-component Perinatal Safety Initiative (PSI), including standardized EFM training	Tertiary care medical center in New York delivering approximately 5300 infants annually The interdisciplinary obstetric team at this facility comprises attending maternal-fetal medicine, attending obstetrical, residents, PAs, RNs, anesthesiologists, and neonatologists. Therefore, the study report did not include the actual number of participants engaged in the PSI.	None	Defined as passing the required competency evaluation for FHR interpretation, however, the required score was not provided in the study report.	A longitudinal quasi-experimental study. The entire interdisciplinary team engaged in all components of the intervention. The PSI intervention included team STEPPS training, multi-discipline teaching rounds, EFM educational e-learning course and evaluation, required documentation for EFM tracing interpretation nomenclature, obstetric emergency simulations, and evidence-based clinical management protocols. Used MAOIs to determine the post-interventional effect of PSI. The individual MAOIs comprised maternal (maternal death, admitted to higher-level care, uterine rupture, peripartum hysterectomy, and return to OR) and fetal/neonatal (stillbirth, neonatal death, 5 min APGAR <7, iatrogenic prematurity, and birth trauma) indicators. MAOIs gathered post-intervention in quartile periods in 2008 & 2009	MAOIs significantly decreased in the first year and were sustained in the 2nd year post-intervention. However, only the specific MAOI improvements were noted in the reduced rates for returning to the operating room (p<.018) and fewer birth traumas (p<.0022).

Table II.2

Reported criteria specific to training and evaluation

Criteria	**Adequate Description**	**Lacking Description**
Type of Curriculum	Cusanza et al., 2020; Thellesen et al., 2017; Wagner et al., 2012	Govindappagari et al., 2016; Carbonne & Sabri-Kaci, 2015; Keegan et al., 2016; Jomeen et al., 2019
Described curriculum	Thellesen et al., 2017; Jomeen et al., 2019; Govindappagari et al., 2015; Wagner et al., 2012	Keegan et al., 2015; Cusanza et al., 2020
Use of Educational Theory	Cusanza et al., 2020; Keegan et al., 2016; Thellesen et al., 2017; Tomlinson et al., 2020	Carbonne & Sabri-Kaci, 2015; Jomeen et al., 2019; Govindappagari et al., 2015; Wagner et al., 2012
Education and evaluation specifically focused on EFM tracing interpretation	Training and Evaluation: Thellesen et al., 2017; Keegan et al., 2016; Govindappagari et al., 2016,	Jomeen et al., 2020; Wagner et al., 2012
Use of researched outcome measurement tools	Thellesen et al., 2017; Tomlinson et al., 2020; Cusanza et al., 2020	Carbonne et al., 2015; Keegan et al., 2016; Jomeen et al., 2019; Wagner et al., 2012

Table III.1

Components of Publications Included in Concept Analysis

Author/Year	Country of Origin	Design	Purpose of paper	Conclusions
Casida, J., Abshire, M., Widmar, B., Combs, P., Freeman, R., & Baas, L. (2018)	United States	Exploratory correlational research design	Described how nurses viewed competence in Ventricular Assist Devices (VAD) and how they integrated available resources to manage patient care.	Nurses in critical care units self-reported higher levels of competence than peers working in progressive care units.
Crozier, K., Sinclair, M., Kernohan, W.G., & Porter, S. (2006)	England	Concept analysis	To describe nurse midwife competencies in birth technologies supporting laboring women.	Provisional attributes of the concept were defined as being related to interpersonal skills, professional knowledge, and clinical proficiency.
da Silva, R.C., & Ferreira, M.A. (2011)	Brazil	Descriptive qualitative study	Characteristics of nurses working in intensive care settings were described with specific consideration for social representations of technology.	Clinical competence raises the assessment of cognitive and psychomotor nurse skills.
Konguswan, W., & Locsin, R. (2011)	Thailand	Descriptive qualitative study	To describe Thai nurses' experiences caring for patients with life-sustaining technologies.	Nurses value care competence despite unease using technologies.
Phillips, J. (2019)	United States	Literature review	To provide an overview of necessary steps when considering selection, risks, and management of healthcare technologies.	The New World Kirkpatrick Model can assist nurse leaders to successfully adopt healthcare technologies into care.

Table III.2

Concept Surrogate Terms and Related Concepts

Concept of study	**Surrogate terms**	**Related concepts**
Nurse competence in diagnostic functions	Technological competence	Ventricular Assistive Device (VAD) competence
	Complex medical technology competence	Birth technology competence
	Competency verification	

Table III.3

Concept Key and Contributing Attributes

Key attributes	Contributing attributes
• Commitment	• ability to integrate patient preferences • respect for and privacy of patient in use of machines • compassionate caring with use of technology team relationship skills
• Capable and willing individuals	• technical and clinical knowledge • psychomotor skills • adequate nursing clinical experience • ability to perform clinical interventions • communication skills • competence maintenance
• Meaningful skills	• observant, fast, and dynamic • professional connection and interface with the machine • excellent judgment
• Positive attitude	• readiness for use • proficiency with technologies seen as expression of caring • advocates for acceptance for technology use

Table III.4

Concept Antecedents

Identified antecedents	
Implementation practices	• Adoption processes • Education on use of technology
Promoting Enthusiastic Attitudes	• Addressing nurse insecurities • Recognizing personal characteristics

Table III.5

Concept Consequences

Identified consequences	
Improved Nurse Competence	• Higher levels of knowledge in technologies • Enhanced communication • Holistic care practices
Improved Team Communication	• Detailed patient physiological data • Enhances collaboration between technology, caregiver, and patient
Caring Practices	• Technology integrated appropriate supports caring • Technology integrated inappropriately dehumanizes or depersonalizes caring

Table IV.1

Demographic characteristics of the sample

Characteristic		Group Control (*n*=11)	Group Intervention (*n*=12)	*p*	ϕ[a]
Education [%, (n)]	Diploma (RN)	0(0)	8(1)	1.000b	.36[e]
	AD (RN)	9(1)	0(0)		
	BA/BS (RN)	91(10)	83(10)		
	Resident (MD)	0(0)	8(1)		
Highest EFM Training [%, (n)]	Non-standardized	0 (0)	17 (2)	.833[b]	.33[e]
	AWHONN EFM Basic	18 (2)	8 (1)		
	AWHONN EFM Intermediate	36 (4)	25 (3)		
	AWHONN EFM Advanced	36 (4)	42 (5)		
	AWHONN EFM Instructor	9 (1)	8 (1)		
Certified [%, (n)]	Yes	82(9)	83(10)	1.000[b]	.02[e]
	No	18(2)	17(2)		
Clinical experience [years; M, (SD)]		15.2 (17.19)	9.8 (7.25)	.368[c, d]	-.20[f]
Obstetrical experience [years; M, (SD)]		12.8 (15.44)	8.8 (9.32)	.469[c, d]	-.16[f]
Baseline competence score [M, (SD)]		72.9 (6.36)	75.5 (3.58)	.252[c, d]	.26[f]

[a]Measure of association
[b]Fisher's exact test
[c]Welch's *t*-test
[d]Judged to be normally distributed by the Anderson-Darling, Shapiro-Francia, and Shapiro-Wilk test (*p*>.15)
[e]Cramer's V
[f]Point biserial correlation
Alpha *p*<.05
Association of Women's Health, Obstetric, and Neonatal Nurses (AWHONN)

Table IV.2

Between group summative score comparison at three points

	Control	Intervention	*p*
Baseline [M (SD)]	72.9(6.36)	75.5(3.58)	.252[a]
Month 1 [M (SD)]	73.6(6.12)	80.2(3.13)	**.006[a]**
Month 3 [M (SD)]	73.8(5.14)	77.1(4.68)	.128[a]

[a]Welch's *t*-test
Bolded is alpha p<.05

Table IV.3

Repeated measure ANOVA pairwise comparisons for time

Time 1	Time 2	n_1	n_2	Greenhouse-Geisser statistic	*df*	*p*
Baseline	Month 1	23	23	-3.25	22	**.004**
Baseline	Month 3	23	23	-1.36	22	.188
Month 1	Month 3	23	23	1.56	22	.133

Bolded is alpha $p<.05$

Table IV.4

Repeated measure ANOVA group comparisons for time

Group	df_n	df_d	*F-statistic*	Greenhouse-Geisser statistic	*p*
Control	2	20	0.322	0.005	.729
Intervention	2	22	6.753	0.216	**.005**

Bolded is alpha $p<.05$

Table IV.5

Pairwise comparisons (Bonferroni adjustment) between time points for each group

Group	Time 1	Time 2	n_1	n_2	t-statistic	df	p
Control	Baseline	Month 1	11	11	-0.803	10	1.000
Control	Baseline	Month 3	11	11	0.673	10	1.000
Control	Month 1	Month 3	11	11	-0.141	10	1.000
Intervention	Baseline	Month 1	12	12	-3.883	11	**.008**
Intervention	Baseline	Month 3	12	12	-1.192	11	.774
Intervention	Month 1	Month 3	12	12	2.30	11	.126

Table IV.6

Pairwise comparisons (Bonferroni adjustment) for three time points

Time 1	Time 2	n_1	n_2	*t*-statistic	*df*	*p*
Baseline	Month 1	23	23	3.25	22	**.011**
Baseline	Month 3	23	23	-1.36	22	.564
Month 1	Month 3	23	23	1.56	22	.399

Table IV.7

Comparison of correct responses to interpretation questions between control and intervention groups

Tracing	Question	Correct Response	P-value Intervention	P-value Time	Relative Risk (95% Wald Confidence Intervals) Intervention	Month1[a]	Month 3[a]
1	FHR Baseline	Normal	.598	.238	0.5 (0.04, 6.24)	--[b]	--[b]
	FHR Variability	Moderate	.634	.832	0.4 (0.01, 15.70)	1.8 (0.21, 14.77)	1.0 (0.14, 7.29)
	FHR Accelerations	Absent	--[c]	--[c]	--[c]	--[c]	--[c]
	FHR Decelerations	None	--[c]	--[c]	--[c]	--[c]	--[c]
	Classification	Category I	.823	.888	0.8 (0.09, 6.54)	1.0 (0.18, 5.47)	0.7 (0.13, 3.69)
2	FHR Baseline	Normal	--[c]	--[c]	--[c]	--[c]	--[c]
	FHR Variability	Moderate	.177	**.029**	3.7 (0.52, 27.04)	0.7 (0.17, 3.37)	8.0 (0.93, 69.04)
	FHR Accelerations	15x15	--[c]	--[c]	--[c]	--[c]	--[c]
	FHR Decelerations	None	--[c]	--[c]	--[c]	--[c]	--[c]
	Classification	Category I	.913	.159	0.9 (0.06, 13.01)	0.4 (0.07, 2.80)	3.3 (0.33, 34.48)
3	FHR Baseline	Normal	--[c]	--[c]	--[c]	--[c]	--[c]
	FHR Variability	Moderate	.966	**.044**	1.1 (0.00, 471.19)	226.8 (0.41, 125659.80)	31.0 (0.19, 5038.85)
	FHR Accelerations	Absent	--[c]	--[c]	--[c]	--[c]	--[c]
	FHR Decelerations	Early	.255	.418	0.4 (0.08, 1.98)	0.4 (0.09, 1.97)	1.0 (0.19, 5.17)
	Classification	Category I	.847	.674	1.2 (0.16, 9.39)	0.6 (0.12, 2.56)	1.0 (0.21, 4.67)
4	FHR Baseline	Bradycardic	--[c]	--[c]	--[c]	--[c]	--[c]
	FHR Variability	Minimal	.992	.398	1.0 (0.00, 2607.10)	0.0 (0.00, 28.43)	0.0 (0.00, 28.44)
	FHR Accelerations	Absent	--[c]	--[c]	--[c]	--[c]	--[c]
	FHR Decelerations	None	--[c]	--[c]	--[c]	--[c]	--[c]
	Classification	Category II	.984	**.043**	0.0 (0.00, 76283355.00)	16283802.9 (0.20, 1309528540740038.00)	16283802.9 (0.20, 1303714013688443.00)
5	FHR Baseline	Indeterminate	--[d]	--[d]	--[d]	--[d]	--[d]
	FHR Variability	Marked	**.016**	.686	4.4 (1.22, 19.04)	0.6 (0.12, 2.55)	0.6 (0.12, 2.55)
	FHR Accelerations	Absent	.789	.432	3.3 (0.00, 34514.81)	0.1 (0.00, 18.94)	1.0 (0.01, 135.66)
	FHR Decelerations	Prolonged	.699	**.004**	3.4 (0.01, 1802.51)	6211.3 (3.35, 11512193.82)	6211.3 (3.35, 11515300.48)
	Classification	Category II	.904	**.043**	0.7 (0.01, 81.91)	10.5 (0.32, 342.55)	0.2 (0.01, 3.56)
6	FHR Baseline	Bradycardic	--[c]	--[c]	--[c]	--[c]	--[c]
	FHR Variability	Minimal	.605	.691	0.6 (0.10, 3.95)	1.4 (0.28, 7.22)	2.1 (0.37, 12.11)
	FHR Accelerations	15x15	--[c]	--[c]	--[c]	--[c]	--[c]
	FHR Decelerations	None	--[c]	--[c]	--[c]	--[c]	--[c]
	Classification	Category II	.266	.752	5.7 (0.31, 106.98)	1.0 (0.10, 10.13)	2.5 (0.16, 39.43)
7	FHR Baseline	Indeterminate	--[d]	--[d]	--[d]	--[d]	--[d]
	FHR Variability	Marked	**.029**	.221	15.4 (0.79, 301.29)	4.3 (0.70, 26.49)	3.0 (0.52, 17.86)
	FHR Accelerations	Absent	.898	.593	1.5 (0.00, 646.10)	1.0 (0.02, 44.30)	0.2 (0.00, 8.94)
	FHR Decelerations	Variable	.753	.401	3.7 (0.00, 19175.26)	25.4 (0.03, 18613.70)	1.0 (0.01, 80.43)
	Classification	Category II	--[d]	--[d]	--[d]	--[d]	--[d]

Table IV.7, Continued

Tracing	Question	Correct Response	P-value Intervention.	Time	Relative Risk (95% Wald Confidence Intervals) Intervention	Month1[a]	Month 3[a]
8	FHR Baseline	Normal	--[d]	--[d]	--[d]	--[d]	--[d]
	FHR Variability	Minimal	.683	**.004**	5.5 (0.00, 35956.24)	19498.0 (1.34, 284093862.14)	1.0 (0.02, 54.98)
	FHR Accelerations	Absent	--c	--c	--[c]	--[c]	--[c]
	FHR Decelerations	None	--c	--c	--[c]	-[c]	--[c]
	Classification	Category II	--[d]	--[d]	--[d]	--[d]	--[d]
9	FHR Baseline	Indeterminate	--[e]	--[e]	--[e]	--[e]	--[e]
	FHR Variability	Marked	**.024**	**.007**	13.0 (0.71, 235.45)	34.2 (1.60, 729.36)	4.5 (0.63, 2.69)
	FHR Accelerations	Absent	.708	.598	2.9 (0.01, 754.23)	1.0 (0.02, 50.34)	0.2 (0.00, 9.41)
	FHR Decelerations	Late	--[d]	--[d]	--[d]	--[d]	--[d]
	Classification	Category II	.816	.593	1.9 (0.01, 473.53)	0.2 (0.00, 9.34)	1.0 (0.02, 50.91)
10	FHR Baseline	Tachycardic	--[f]	--[f]	--[f]	--[f]	--[f]
	FHR Variability	Minimal	--[d]	--[d]	--[d]	--[d]	--[d]
	FHR Accelerations	Absent	--[c]	--[c]	--[c]	--[c]	--[c]
	FHR Decelerations	Late	--[d]	--[d]	--[d]	--[d]	--[d]
	Classification	Category II	.284	.165	20.8 (0.42, 1034.22)	2.0 (0.18, 21.48)	16.9 (0.33, 877.04)
11	FHR Baseline	Indeterminate	--[e]	--[e]	--[e]	--[e]	--[e]
	FHR Variability	Marked	--[e]	--[e]	--[e]	--[e]	--[e]
	FHR Accelerations	Absent	--[e]	--[e]	--[e]	--[e]	--[e]
	FHR Decelerations	Prolonged	--[d]	--[d]	--[d]	--[d]	--[d]
	Classification	Category II	--[e]	--[e]	--[e]	--[e]	--[e]
12	FHR Baseline	Tachycardic	--[e]	--[e]	--[e]	--[e]	--[e]
	FHR Variability	Absent	--[c]	--[c]	--[c]	--[c]	--[c]
	FHR Accelerations	Absent	--[c]	--[c]	--[c]	--[c]	--[c]
	FHR Decelerations	None	--[c]	--[c]	--[c]	--[c]	--[c]
	Classification	Category II	.845	**.041**	1.9 (0.00, 1564.76)	406.4 (0.03, 5283783.15)	60.3 (0.01, 337128.91)
13	FHR Baseline	Tachycardic	--[f]	--[f]	--[f]	--[f]	--[f]
	FHR Variability	Moderate	--[e]	--[e]	--[e]	--[e]	--[e]
	FHR Accelerations	15x15	--[c]	--[c]	--[c]	--[c]	--[c]
	FHR Decelerations	None	--[c]	--[c]	--[c]	--[c]	--[c]
	Classification	Category II	--[e]	--[e]	--[e]	--[e]	--[e]
14	FHR Baseline	Tachycardic	--[c]	--[c]	--[c]	--[c]	--[c]
	FHR Variability	Moderate	.648	.712	2.9 (0.03, 266.88)	1.0 (0.05, 21.71)	0.4 (0.02, 7.10)
	FHR Accelerations	Absent	--[c]	--[c]	--[c]	--[c]	--[c]
	FHR Decelerations	Variable	--[c]	--[c]	--[c]	--[c]	--[c]
	Classification	Category II	--[d]	--[d]	--[d]	--[d]	--[d]
15	FHR Baseline	Sinusoidal	.191	.256	2.7 (0.60, 12.11)	2.9 (0.65, 13.14)	1.0 (0.26, 3.88)
	FHR Variability	Indeterminate	--[f]	--[f]	--[f]	--[f]	--[f]
	FHR Accelerations	Absent	--[c]	--[c]	--[c]	--[c]	--[c]
	FHR Decelerations	None	--[c]	--[c]	--[c]	--[c]	--[c]
	Classification	Category III	**.002**	**.047**	71.4 (2.07, 2461.21)	4.4 (0.50, 37.70)	16.8 (1.01, 278.66)

Table IV.7, Continued

Tracing	Question	Correct Response	P-value Intervention	P-value Time	Relative Risk (95% Wald Confidence Intervals) Intervention	Month1[a]	Month 3[a]
16	FHR Baseline	Normal	--[c]	--[c]	--[c]	--[c]	--[c]
	FHR Variability	Absent	--[e]	--[e]	--[e]	--[e]	--[e]
	FHR Accelerations	Absent	--[c]	--[c]	--[c]	--[c]	--[c]
	FHR Decelerations	Variable	.795	.613	1.3 (0.15, 11.83)	1.5 (0.24, 9.84)	2.7 (0.34, 21.71)
	Classification	Category III	.981	.234	1.1 (0.02, 59.64)	0.2 (0.01, 3.71)	0.1 (0.00, 2.69)
17	FHR Baseline	Bradycardic	--[e]	--[e]	--[e]	--[e]	--[e]
	FHR Variability	Absent	--[c]	--[c]	--[c]	--[c]	--[c]
	FHR Accelerations	Absent	--[c]	--[c]	--[c]	--[c]	--[c]
	FHR Decelerations	None	--[c]	--[c]	--[c]	--[c]	--[c]
	Classification	Category I	--[c]	--[c]	--[c]	--[c]	--[c]

Bolded values show statistical evidence of a difference using a likelihood ratio test $\chi^2_{(1)}$
[a]Relative to baseline
[b]Unestimable
[c]All responses 100%, cannot be modeled
[d]Lack of convergence is an indication the data do not fit the model well, because there are too many poorly fitting observations. The most likely cause of this is there are not enough observations to estimate all the terms.
[e]Singularity implies variances of one or more linear combinations of treatment of time (main effects) are close to zero or equal zero
[f]Quasi-separation occurred during the modelling process i.e., some observations were predicted to be correct (1) and incorrect (0)
Significance results (*p*<.05) are bolded in the table.

Table IV.8

Between group comparison of self-efficacy scores

Time	Self-efficacy questions	Control	Treatment	p^a	p^b
Baseline	It is easy for me to interpret EFM tracings. [Mdn (IQR)]	6 (1.5)	6 (1)	.195	.157
	I have the capacity to interpret EFM tracings. [Mdn (IQR)]	6 (2)	6 (1)	.391	.959
	I do not feel comfortable interpreting EFM tracings. [Mdn (IQR)]	2 (2)	2 (0)	.884	.949
	I worry I might interpret the tracing incorrectly and risk preventing adverse neonatal outcomes. [Mdn (IQR)]	5 (3)	3 (2)	.251	.759
Month 1	It is easy for me to interpret EFM tracings. [Mdn (IQR)]	6 (1)	6 (0)		
	I have the capacity to interpret EFM tracings. [Mdn (IQR)]	6 (2)	6 (1)		
	I do not feel comfortable interpreting EFM tracings. [Mdn (IQR)]	2 (3)	2 (0)		
	I worry I might interpret the tracing incorrectly and risk preventing adverse neonatal outcomes. [Mdn (IQR)]	3 (2)	3 (2.25)		
Month 3	It is easy for me to interpret EFM tracings. [Mdn (IQR)]	6 (1)	6 (0.25)		
	I have the capacity to interpret EFM tracings. [Mdn (IQR)]	6 (1)	6 (0.25)		
	I do not feel comfortable interpreting EFM tracings. [Mdn (IQR)]	2 (2.5)	2 (0)		
	I worry I might interpret the tracing incorrectly and risk preventing adverse neonatal outcomes. [Mdn (IQR)]	4 (3)	3 (2.25)		

[a]Test for difference in groups
[b]Test for difference in time
Likert scale: 1) strongly disagree, 2) disagree, 3) somewhat disagree, 4) neutral, 5) somewhat agree, 6) agree, and 7) strongly agree.

Table IV.9

Feasibility responses from intervention group participants (n=12)

	Month 3	
	Mean (SD)	Mdn (IQR)
What is your willingness to towards engaging in a Simulation-Based Mastery Learning intervention during future EFM competence evaluations?	4.1(0.67)	4 (0.25)
To what degree do you feel your attitudes towards the SBML with DP EFM competence intervention influenced your EFM competence?	3.4 (0.90)	3.5 (1)

Likert scale: 1) extremely unlikely, 2) unlikely, 3) neutral, 4) likely, and 5) extremely likely.

Appendix IV.A

Percentage (and frequency) of correct interpretation responses to tracing questions for participants completing evaluations

Tracing	Question	Correct Response	Control *Baseline*	Control *Month 1*	Control *Month 3*	Intervention *Baseline*	Intervention *Month 1*	Intervention *Month 3*
1	FHR Baseline	Normal	100(11)	91(10)	100(11)	25(3)	92(11)	92(11)
	FHR Variability	Moderate	82(9)	73(8)	91(10)	75(9)	92(11)	67(8)
	FHR Accelerations	Absent	100(11)	100(11)	100(11)	100(12)	100(12)	100(12)
	FHR Decelerations	None	100(11)	100(11)	100(11)	100(12)	100(12)	100(12)
	Classification	Category I	82(9)	73(8)	82(9)	75(9)	83(10)	67(8)
2	FHR Baseline	Normal	100(11)	100(11)	100(11)	100(12)	100(12)	100(12)
	FHR Variability	Moderate	55(6)	55(6)	91(10)	83(10)	75(9)	92(11)
	FHR Accelerations	15x15	100(11)	100(11)	100(11)	100(12)	100(12)	100(12)
	FHR Decelerations	None	100(11)	100(11)	100(11)	100(12)	100(12)	100(12)
	Classification	Category I	82(9)	73(8)	91(10)	83(10)	75(9)	92(11)
3	FHR Baseline	Normal	100(11)	100(11)	100(11)	100(12)	100(12)	100(12)
	FHR Variability	Moderate	73(8)	91(10)	91(10)	83(10)	92(11)	83(10)
	FHR Accelerations	Absent	100(11)	100(11)	100(11)	100(12)	100(12)	100(12)
	FHR Decelerations	Early	73(8)	91(10)	91(10)	92(11)	50(6)	75(9)
	Classification	Category I	55(6)	64(7)	64(7)	75(9)	50(6)	67(8)
4	FHR Baseline	Bradycardic	100(11)	100(11)	100(11)	100(12)	100(12)	100(12)
	FHR Variability	Minimal	91(10)	91(10)	91(10)	100(12)	92(11)	92(11)
	FHR Accelerations	Absent	100(11)	100(11)	100(11)	100(12)	100(12)	100(12)
	FHR Decelerations	None	100(11)	100(11)	100(11)	100(12)	100(12)	100(12)
	Classification	Category II	91(10)	91(10)	91(10)	92(11)	100(12)	100(12)
5	FHR Baseline	Indeterminate	0(0)	45(5)	18(2)	8(1)	92(11)	42(5)
	FHR Variability	Marked	73(8)	64(7)	55(6)	92(11)	83(10)	92(11)
	FHR Accelerations	Absent	82(9)	82(9)	91(10)	100(12)	92(11)	92(11)
	FHR Decelerations	Prolonged	55(6)	73(8)	91(10)	75(9)	8(1)	92(11)
	Classification	Category II	91(10)	82(9)	82(9)	75(9)	100(12)	67(8)
6	FHR Baseline	Bradycardic	100(11)	100(11)	100(11)	92(11)	100(12)	100(12)
	FHR Variability	Minimal	91(10)	82(9)	82(9)	67(8)	83(10)	92(11)
	FHR Accelerations	15x15	100(11)	100(11)	91(10)	100(12)	100(12)	100(12)
	FHR Decelerations	None	100(11)	100(11)	100(11)	100(12)	100(12)	100(12)
	Classification	Category II	91(10)	82(9)	91(10)	92(11)	100(12)	100(12)

Appendix IV.A, Continued

Tracing	Question	Correct Response	Control Baseline	Control Month 1	Control Month 3	Intervention Baseline	Intervention Month 1	Intervention Month 3
7	FHR Baseline	Indeterminate	0(0)	18(2)	9(1)	0(0)	75(9)	42(5)
	FHR Variability	Marked	27(3)	18(2)	27(3)	33(4)	75(9)	58(7)
	FHR Accelerations	Absent	91(10)	91(10)	82(9)	92(11)	92(11)	92(11)
	FHR Decelerations	Variable	91(10)	91(10)	9(1)	92(11)	100(12)	100(12)
	Classification	Category II	100(11)	100(11)	100(11)	92(11)	100(12)	100(12)
8	FHR Baseline	Normal	100(11)	100(11)	91(10)	100(12)	100(12)	100(12)
	FHR Variability	Minimal	73(8)	91(10)	73(8)	92(11)	100(12)	92(11)
	FHR Accelerations	Absent	100(11)	100(11)	100(11)	100(12)	100(12)	100(12)
	FHR Decelerations	None	100(11)	100(11)	100(11)	100(12)	100(12)	100(12)
	Classification	Category II	82(9)	100(11)	91(10)	100(12)	100(12)	100(12)
9	FHR Baseline	Indeterminate	0(0)	45(5)	45(5)	0(0)	100(12)	58(7)
	FHR Variability	Marked	45(5)	91(10)	73(8)	83(10)	100(12)	92(11)
	FHR Accelerations	Absent	100(11)	91(10)	82(9)	92(11)	100(12)	100(12)
	FHR Decelerations	Late	100(11)	100(11)	100(11)	100(12)	50(6)	92(11)
	Classification	Category II	100(11)	82(9)	100(11)	92(11)	100(12)	92(11)
10	FHR Baseline	Tachycardic	100(11)	100(11)	100(11)	100(12)	92(11)	100(12)
	FHR Variability	Minimal	82(9)	82(9)	91(10)	100(12)	100(12)	100(12)
	FHR Accelerations	Absent	100(11)	100(11)	100(11)	100(12)	100(12)	100(12)
	FHR Decelerations	Late	100(11)	100(11)	100(11)	100(12)	83(10)	83(10)
	Classification	Category II	73(8)	73(8)	91(10)	92(11)	100(12)	100(12)
11	FHR Baseline	Indeterminate	0(0)	91(10)	64(7)	8(1)	100(12)	92(11)
	FHR Variability	Marked	100(11)	91(10)	82(9)	100(12)	100(12)	83(10)
	FHR Accelerations	Absent	18(2)	45(5)	36(4)	25(3)	0(0)	0(0)
	FHR Decelerations	Prolonged	0(0)	9(1)	9(1)	0(0)	83(10)	25(3)
	Classification	Category II	100(11)	100(11)	82(9)	92(11)	100(12)	83(10)

Appendix IV.A, Continued

Tracing	Question	Correct Response	Control Baseline	Control Month 1	Control Month 3	Intervention Baseline	Intervention Month 1	Intervention Month 3
12	FHR Baseline	Tachycardic	100(11)	91(10)	91(10)	100(12)	100(12)	100(12)
	FHR Variability	Absent	100(11)	100(11)	100(11)	100(12)	92(11)	100(12)
	FHR Accelerations	Absent	100(11)	100(11)	100(11)	100(12)	100(12)	100(12)
	FHR Decelerations	None	100(11)	100(11)	100(11)	100(12)	100(12)	100(12)
	Classification	Category II	73(8)	73(8)	82(9)	75(9)	100(12)	83(10)
13	FHR Baseline	Tachycardic	100(11)	100(11)	82(9)	100(12)	100(12)	100(12)
	FHR Variability	Moderate	91(10)	100(11)	100(11)	100(12)	100(12)	100(12)
	FHR Accelerations	15x15	100(11)	100(11)	100(11)	100(12)	100(12)	100(12)
	FHR Decelerations	None	100(11)	100(11)	100(11)	100(12)	100(12)	100(12)
	Classification	Category II	91(10)	100(11)	91(10)	100(12)	100(12)	100(12)
14	FHR Baseline	Tachycardic	100(11)	100(11)	100(11)	100(12)	100(12)	100(12)
	FHR Variability	Moderate	82(9)	91(10)	82(9)	100(12)	92(11)	92(11)
	FHR Accelerations	Absent	100(11)	100(11)	100(11)	100(12)	100(12)	100(12)
	FHR Decelerations	Variable	0(0)	0(0)	0(0)	0(0)	8(1)	17(2)
	Classification	Category II	100(11)	100(11)	100(11)	100(12)	100(12)	100(12)
15	FHR Baseline	Sinusoidal	45(5)	64(7)	64(7)	75(9)	92(11)	58(7)
	FHR Variability	Indeterminate	0(0)	45(5)	0(0)	0(0)	92(11)	0(0)
	FHR Accelerations	Absent	100(11)	100(11)	100(11)	100(12)	100(12)	100(12)
	FHR Decelerations	None	100(11)	100(11)	100(11)	100(12)	100(12)	92(11)
	Classification	Category III	45(5)	64(7)	82(9)	92(11)	100(12)	100(12)
16	FHR Baseline	Normal	100(11)	100(11)	100(11)	100(12)	100(12)	100(12)
	FHR Variability	Absent	91(10)	91(10)	100(11)	100(12)	100(12)	92(11)
	FHR Accelerations	Absent	100(11)	100(11)	100(11)	100(12)	100(12)	100(12)
	FHR Decelerations	Variable	82(9)	82(9)	91(10)	83(10)	92(11)	92(11)
	Classification	Category III	91(10)	73(8)	82(9)	92(11)	92(11)	75(9)
17	FHR Baseline	Bradycardic	91(10)	100(11)	100(11)	100(12)	100(12)	100(12)
	FHR Variability	Absent	100(11)	100(11)	100(11)	100(12)	100(12)	100(12)
	FHR Accelerations	Absent	100(11)	100(11)	100(11)	100(12)	100(12)	100(12)
	FHR Decelerations	None	100(11)	100(11)	100(11)	100(12)	100(12)	100(12)
	Classification	Category I	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)

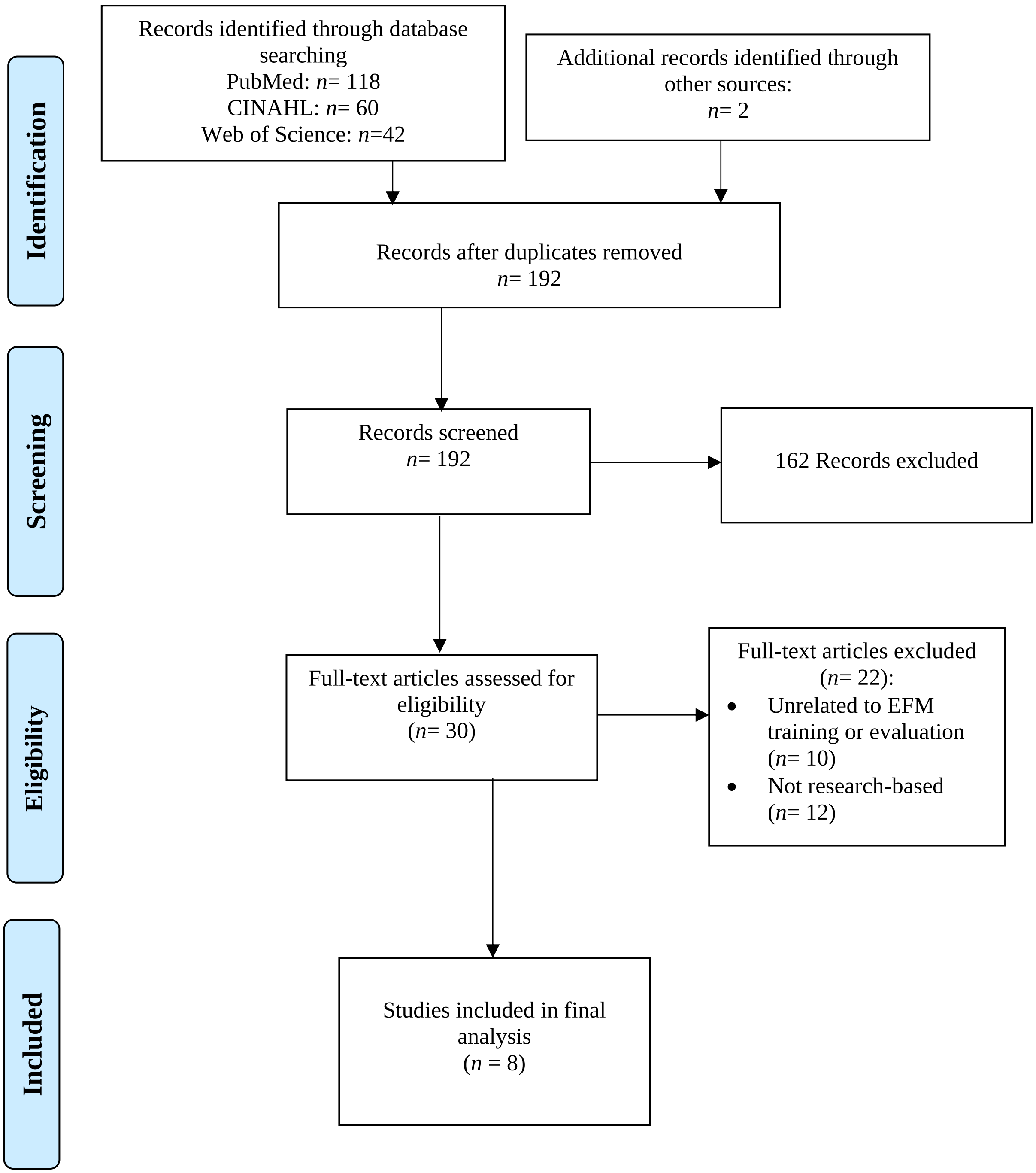
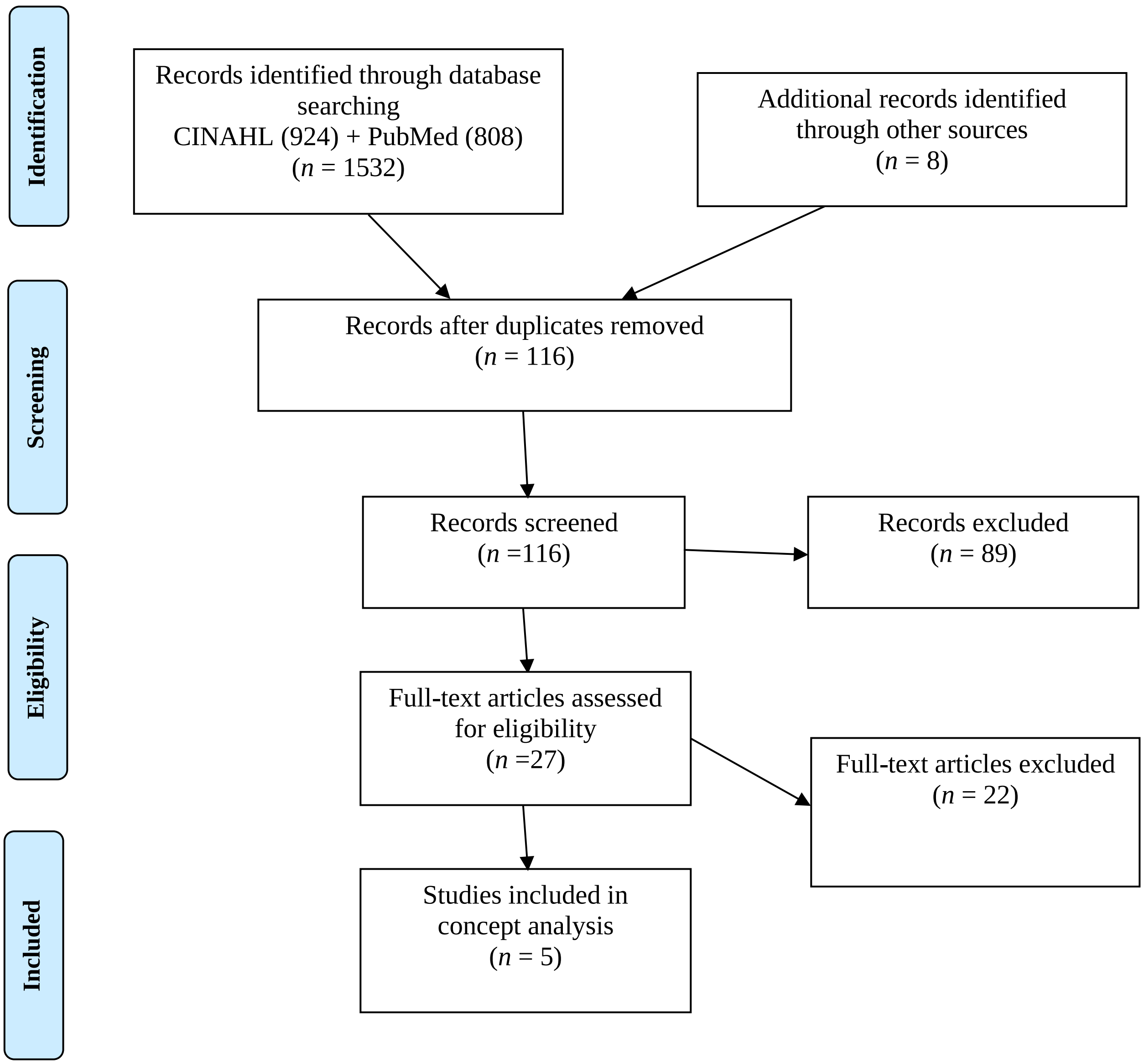


FIGURE II.1

PRISMA Flow Diagram



SOURCE: Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. (2009). Preferred reporting items for systematic reviews and meta-analysis: The PRISMA statement. *Journal of Clinical Epidemiology*, *62*(10), e1-34.

FIGURE III.1

PRISMA Flowchart for Concept Analysis

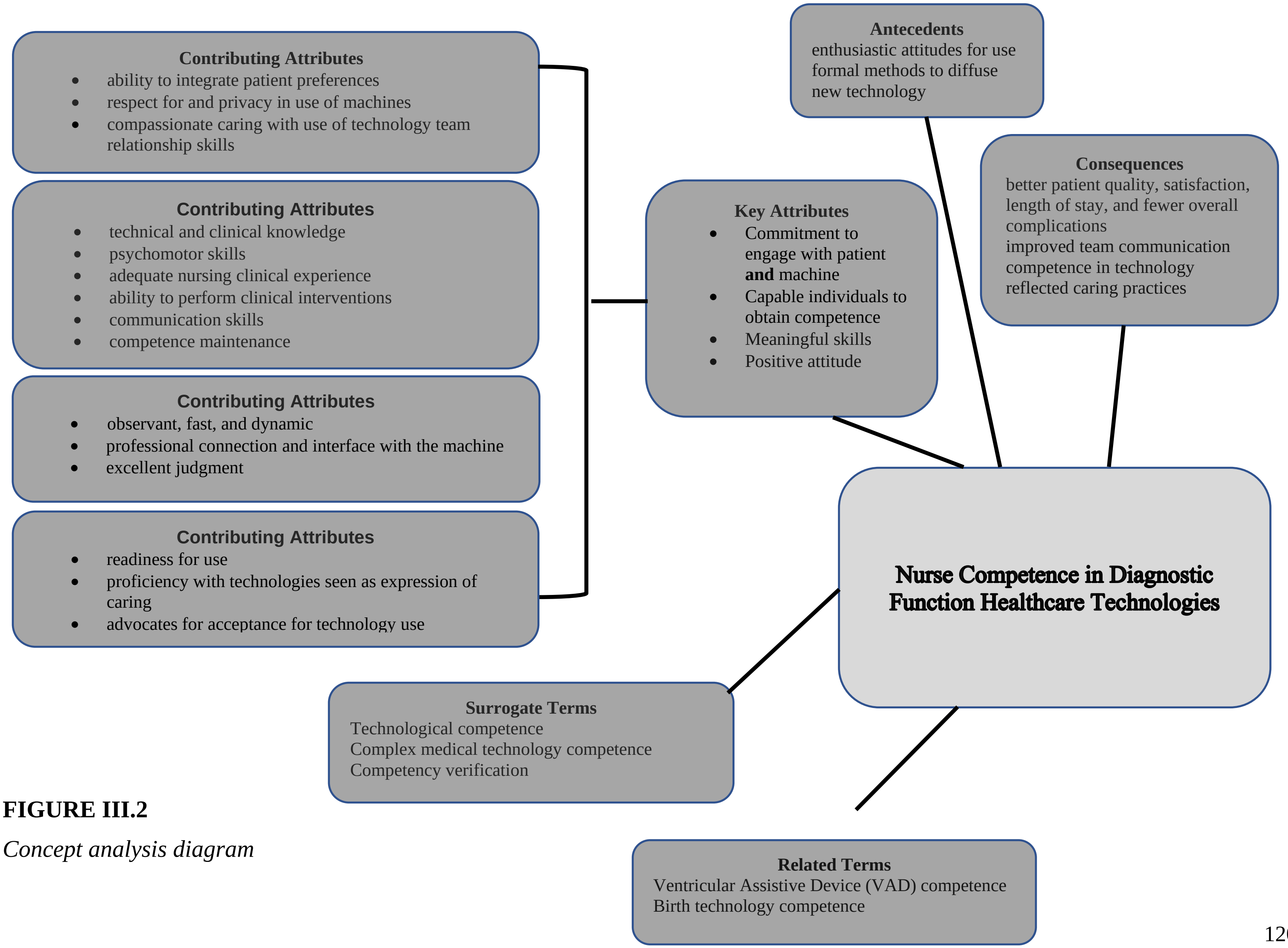


FIGURE III.2

Concept analysis diagram

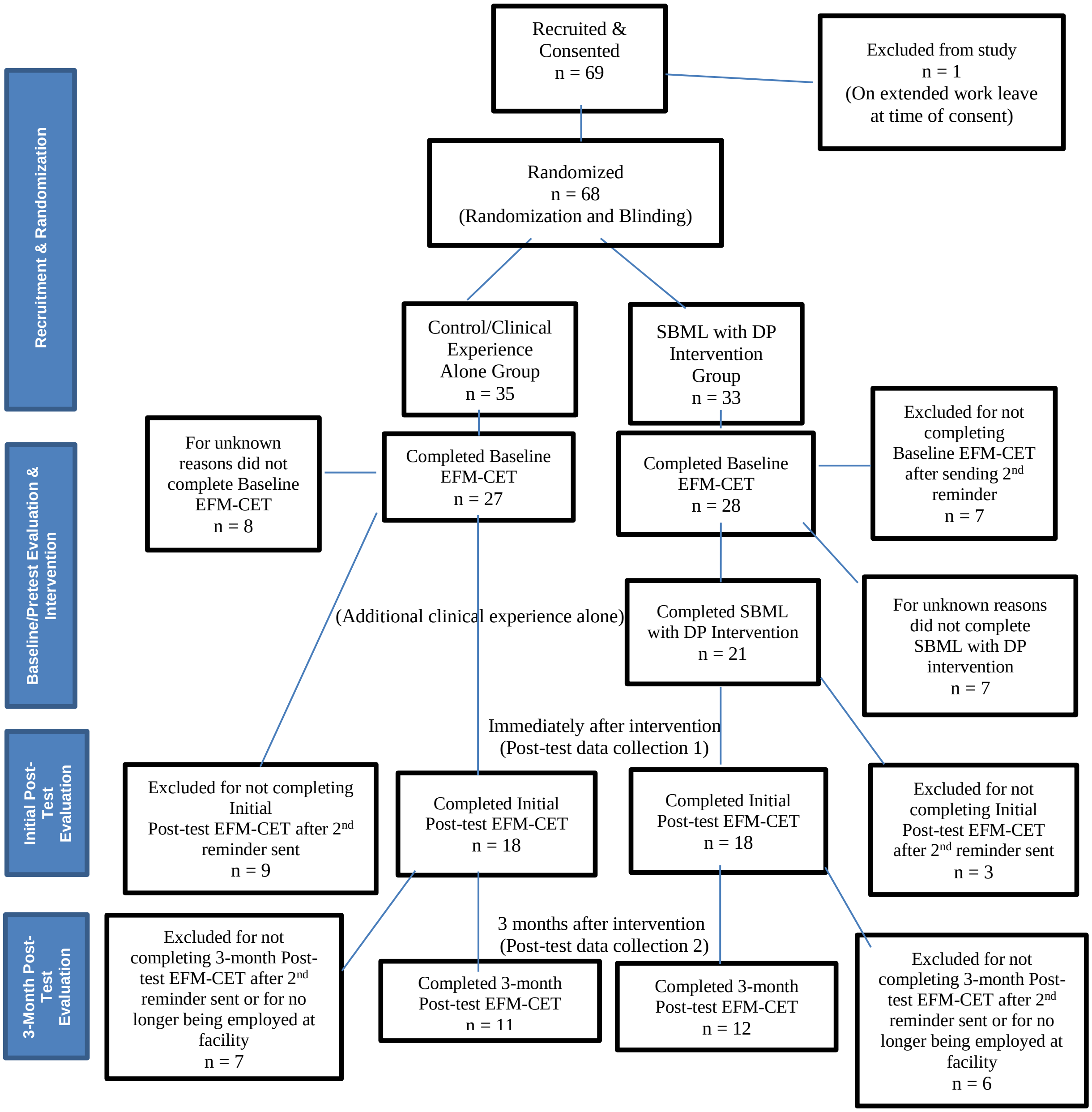


FIGURE IV.1

Consort flow chart of participant's progression through study phases

VITA

Susan Henley Hébert obtained her Bachelor of Science Degree in Nursing (BSN) from Illinois Wesleyan University in Bloomington, Illinois, in 1986. Her clinical nursing career began as a neonatal intensive care nurse. She remained in this position for 15 years while serving as a neonatal outreach educator for perinatal centers in Illinois and Indiana. In addition, Susan spent several years as a school nurse overseeing onsite care for approximately 1200 students. In 2011, she began a position as a simulation educator for Indiana University School of Medicine, leading training for pediatric residents, neonatology fellows, and regional hospital personnel. Susan came to the University of Tennessee, Knoxville, in 2013 to develop a simulation program for the College of Nursing. As her passion for simulation education grew, it initiated a desire to further her education. Susan then obtained a master's degree in medical simulation from Drexel University School of Medicine. Soon after completing this program, she chose to attend the University of Tennessee to pursue a Doctor of Philosophy in nursing. Her research interest in interprofessional competence in interpreting electronic fetal monitors is prompted by caring for neonates who experienced adverse neonatal outcomes resulting from an unexpected event during birth early in her nursing career. After graduation, Susan will continue her career as Simulation Director at the College of Nursing, and she also hopes to build the research foundation initiated in her dissertation study with additional work to ensure competent care for improved patient safety.