ERSKINE, REVA SARAH. Development of an Evaluation Instrument to Assess the Level of User Expertise for the CAD/CAM System for Integral Knitting. (Under the direction of Lisa Parrillo Chapman.)

The objective of the research was to create, pilot test, and validate an evaluation instrument that can be used to determine the knowledge base needed to effectively use the CAD/CAM system to produce an integral knit product. The method for creating the evaluation instrument will use the Delphi Method, review of literature, informal interviews with field experts, and observation, training and practice of integral knitting in order to create a preliminary evaluation instrument. The results helped to refine the evaluation instrument in order to be valid and reliable when used in future research. In future research the evaluation instrument can be used to assess one’s knowledge and level of user expertise in all aspects of integral knitting prior to being trained on the CAD/CAM system for integral knitting. This will be especially useful for those in academia and industry to assess the amount of training needed for new users of the CAD/CAM system for integral knitting.
Development of an Evaluation Instrument to Assess the Level of User Expertise for the CAD/CAM System for Integral Knitting
North Carolina State University

by
Reva Sarah Erskine

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APPROVED BY:

Lisa Parrillo Chapman
Committee Chair

Traci Lamar

Abdel-Fattah Mohamed Seyam

Nancy Powell
Dedication

This thesis is dedicated to my family for their endless love and support throughout not only my thesis preparation, but my entire life.
Biography

Reva Erskine grew up in Weston, FL and has always had a strong interest in apparel and textiles. This led her to major in Fashion at Florida State University, where she obtained a Bachelor’s of Science. She entered graduate school at North Carolina State University, where she earned a Master’s of Science in Textile Technology. She hopes to open an apparel store back in Weston, FL one day.
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# Table of Contents

List of Tables ........................................................................................................... viii
List of Figures ............................................................................................................ ix
Chapter 1: Introduction .............................................................................................. 1
  1.1 Objective of the Study ......................................................................................... 1
  1.2 Relevance ........................................................................................................... 3
  2.1 Introduction to Integral Knitting ........................................................................ 5
    2.1.1 Flat V-bed Knitting Machines for Integral Knitting .................................. 6
    2.1.2 Knitting Technology .................................................................................... 7
    2.1.3 Shaping Capabilities ................................................................................... 9
  2.2 Knitting Development ....................................................................................... 13
  2.3 Integral Knit Product Development .................................................................. 14
    2.3.1 CAD for Integral Knitting .......................................................................... 15
    2.3.2 Fully Fashioned ......................................................................................... 18
    2.3.3 Complete Garment ..................................................................................... 19
    2.3.4 Production Components ............................................................................ 22
    2.3.4.1 Silhouette Development ....................................................................... 23
    2.3.4.2 Knit Structure ....................................................................................... 30
    2.3.4.3 Simulation ............................................................................................. 32
    2.3.4.4 Programming ......................................................................................... 36
  2.4 Learning CAD/CAM ......................................................................................... 37
    2.4.1 Learning Aspects ....................................................................................... 45
  2.5 Training ............................................................................................................. 46
    2.5.1 Training through the Machine Manufacturer ............................................ 47
    2.5.2 Academic Setting ...................................................................................... 48
    2.5.3 High Learning Curve ............................................................................... 50
  2.6 Summary .......................................................................................................... 51
Chapter 3: Methodology ......................................................................................... 52
  3.1 Research Design ............................................................................................... 52
  3.2 Technology Used .............................................................................................. 53
  3.3 Stage 1: Development of the Evaluation Instrument ....................................... 54
3.3.1 Development of the Evaluation Instrument Components ........................................ 58
  3.3.1.1 Preliminary Survey .................................................................................. 58
  3.3.1.2 Direction Manual for Completing a Task ............................................... 65
  3.3.1.3 Post Survey ............................................................................................ 66
  3.3.1.4 Initial Rubric .......................................................................................... 68
3.5 Stage 2: Observation and Testing of Pilot 1 and Pilot 2 ....................................... 70
  3.5.1 Population and Sample for Pilot 1 .............................................................. 71
  3.5.2 Population and Sample for Pilot 2 .............................................................. 71
  3.5.3 Solicitation of Participates for Pilot 1 and Pilot 2 ....................................... 72
  3.5.4 Administration Procedures for Pilot 1 and Pilot 2 ....................................... 73
  3.5.5 Pilot 1 ....................................................................................................... 75
  3.5.6 Pilot 2 ....................................................................................................... 75
3.6 Stage 3: Development of the Validation Procedure ............................................. 76
  3.6.1 Population and Sample of Experts .............................................................. 76
  3.6.2 Informal Interviews ................................................................................... 77
Chapter 4: Results ..................................................................................................... 79
  4.1 Stage 1: Results .............................................................................................. 79
    4.1.1 Yarn and Knit Structure ........................................................................... 80
    4.1.2 Garment Development ........................................................................... 81
    4.1.3 Fashioning ............................................................................................... 82
    4.1.4 Machine Programming .......................................................................... 83
  4.2 Stage 2: Observation and Testing ................................................................. 84
    4.2.1 Pilot 1 .................................................................................................... 85
    4.2.2 Modifications Made to Rubric after Pilot 1 ........................................... 87
    4.2.3 Modifications Made to Preliminary Survey after Pilot 1 ....................... 91
    4.2.4 Modifications to Knowledge Rating Scale ............................................ 92
    4.2.5 Modifications to Direction Manual after Pilot 1 .................................... 93
    4.2.6 Modifications to Post Survey after Pilot 1 ............................................ 94
    4.2.7 Pilot 2 ................................................................................................... 95
  4.3 Stage 3: Validation from Integral Knitting Experts ........................................... 96
Chapter 5: Conclusion and Limitations ..................................................................... 101
  5.1 Limitations ................................................................................................... 101
Chapter 6: Future Research
References
Appendix
Appendix A- Preliminary Survey
Appendix B- Post Survey
Appendix C- Direction Manual
Appendix D- Rubric
Appendix E- Cover Letter
Appendix F- Questions Provided to Industry Experts for Validation

Page counts:
Chapter 6: Future Research .......................................................... 104
References .................................................................................. 106
Appendix ..................................................................................... 115
Appendix A- Preliminary Survey ...................................................... 116
Appendix B- Post Survey ................................................................. 132
Appendix C- Direction Manual ....................................................... 148
Appendix D- Rubric .................................................................. 178
Appendix E- Cover Letter ............................................................... 184
Appendix F- Questions Provided to Industry Experts for Validation ........................................ 185
List of Tables

Table 1. Pilot 1 results ................................................................. 87
Table 2. Time and frequency on the CAD/CAM system for integral knitting for each level of user......................................................... 89
Table 3. Number of testing questions and steps to complete in each knowledge area.......... 90
Figure 1. Model depicting an integral knit design work flow; source: Lisa Chapman based on images from Shima Seiki, 2010 ................................................................. 2
Figure 2. The needle bed of a flat V-bed knitting machine; source: North Carolina State University Textile Resource, weft knitting section ........................................ 8
Figure 3. (a) Single needles narrowing; (b) Single needle widening; (c): Single needles widening and then filled in with a new stitch; source: (Brackenbury, 1992, p.64) ............. 11
Figure 4. Variety of different stitches used for shaping. 1: 2x2 rib; 2:1x1 rib; 3: half cardigan; 4: tubular courses; 5: full cardigan; source: Spencer, 2004, 16.4.7) ........................................... 13
Figure 5. Model of integral knitting CAD/CAM features; source: Shima Seiki, 2010 ........ 15
Figure 6. The fashion marks can be seen on the bottom of the armseve, right next to the arm hole seam ........................................................................................................ 19
Figure 7 a-d. Complete garment: “(a) breakdown of garment components; (b) loop diagram of tubes; (c) finished garments; (d) disposition of garment parts on V-bed flat knitting machine,” source: (Brackenbury, 1992, p. 85) .......................................................................... 21
Figure 8. Fashion marks on the armseye of a complete garment ..................................... 22
Figure 9. Example of a technical flat sketch of a sweater and a fashion figure ...................... 24
Figure 10. Example of a specification (spec) sheet and a costing sheet; source: (Keiser & Garner, 2008, p. 306-307) .......................................................... 25
Figure 11. Shima Seiki’s CAD software’s garment silhouette library; source: Shima Seiki design software .......................................................................................... 30
Figure 12. Close up image of a knit structure on the Shima Seiki CAD software; source: Shima Seiki CAD design system ................................................................. 32
Figure 13. Cable knit structure on a jersey background; source: Shima Seiki CAD design system ........................................................................................................ 32
Figure 14. The software view of Eneas Informatica’s simulation; source: Eneas Informatica, 2010................................................................................................. 35
Figure 15 A detailed example of Eneas Informaticas’s knitwear simulation; source: Eneas Informatica, 2010 .................................................................................. 35
Figure 16. “3D Modelist Software”; source: Shima Seiki, 2010 ................................................ 36
Figure 17. Detail of a simulation of an integrally knitted garment; source: Eneas Informatica, 2010 ........................................................................................................ 36
Figure 18. Example of an open-ended question from the preliminary survey ....................... 60
Figure 19. Three questions from the yarn knowledge area of the preliminary survey .......... 62
Figure 20. Example of a Likert scale from the fashioning section of the preliminary survey 63
Figure 21. Example of a ratio scale question from the preliminary survey .......................... 65
Figure 22. Example of an ordinal interval rating scale from the preliminary survey ............. 93
Figure 23. Example of one of the steps from the direction manual ........................................ 94
Chapter 1: Introduction

Increasing consumer preference for comfort, performance, and aesthetic appeal has driven demand for better designed, higher performance knitted apparel. These preferences have led to several innovations in integral knitting including advancements in software and machinery. Integral knit design is a complex process that requires knowledge of fiber, yarn, knit structure, three dimensional shaping, fit and finishing processes. In more traditional knitting processes, the knit design and technical design are separate activities that require separate designers and technologies. Integral knitting involves complex computer aided design software that drives production equipment and brings technical and aesthetic design into one process. As shown in figure 1, a typical integral knitwear development workflow for apparel would involve selection of the silhouette or style and decisions on fabric structure, yarn and sizing. Computer aided design (CAD) and computer aided manufacturing (CAM) software developed for this purpose would ideally simulate the end product as well as provide technical information to drive the production equipment. However, there is a low user rate of the CAD/CAM system for integral knitting which slows the effective adoption of this complex technology.

1.1 Objective of the Study

The objective of the research was to create, pilot test, and validate an evaluation instrument that can be used to determine the knowledge base needed to effectively use a CAD/CAM system to produce an integral knit product. This evaluation instrument comprises a preliminary survey, a direction manual, a post survey, and a rubric. The instrument developed in this work focused on the Shima Seiki SDS-One CAD/CAM system. It is hoped
that members of academia and industry will be able to use this evaluation instrument in future research to assess a potential user’s knowledge and skill level in all aspects of integral knitting, which would be useful prior to conducting training on the CAD/CAM system for integral knitting. The knowledge base findings can be used to categorize the CAD/CAM user as expert, intermediate, or novice. The instrument can also serve as a model for developing similar evaluation instruments, as much of the instrument developed in this research is adaptable for other CAD/CAM systems. This research is part of a larger research project sponsored by the National Textile Center (NTC) that seeks to “develop an expert knowledge base incorporating yarn structure, knit structure, end product requirements and finishing, and to create an integrated system for the design, visualization, development and production of engineered knitted garments” (Lamar, Powell, & Parrillo-Chapman, 2009, p. 1).

Figure 1. Model depicting an integral knit design work flow; source: designed by Lisa Parrillo Chapman based on the Shima Seiki model, 2010.
1.2 Relevance

One goal of the larger NTC project is to “complete an analysis of the current status of existing processes including examination of different approaches, successes and barriers to integration and implementation, and gaps to be addressed” (Lamar et al., 2009, p. 5). The high learning curve for the CAD/CAM system for integral knitting was identified by the principal investigators as a barrier for adoption and optimization of the technology. Therefore, results of this study will contribute to the goals of the larger project and assist industry and academia by providing an evaluation instrument which can assess the level of user expertise prior to training. The evaluation instrument may be useful to improve training and utilization of the system. Assessing a new user of the CAD/CAM system for integral knitting with this evaluation instrument—understanding what knowledge the user already has and what knowledge needs to be further learned—allows training sessions to be more efficient and facilitates planning an appropriate amount and length of training.

As part of this study, the researcher completed 120 hours of CAD/CAM training for integral knitting, conducted a literature review that focused in part on how users effectively learn and use CAD, utilized the Delphi Method, and conducted informal interviews. After reviewing the literature, assessing the CAD/CAM system for integral knitting, and examining how the system fits into the product development process, it was clear that the software needs to be taught and understood correctly by users in order for them to efficiently and accurately design and produce an integrally knit garment. In order to understand how to efficiently and effectively teach/learn the integral knitting software, it was crucial to first find out what knowledge is needed to use the CAD/CAM system. Understanding what knowledge is
needed to use the CAD/CAM system was the goal of developing the evaluation instrument created in this research.
Chapter 2: Literature Review

The review of the literature focuses on terminology and concepts associated with the product development process for integral knitting using a CAD/CAM system. The primary researcher’s review seeks to provide an introduction to integral knitting, an overview of the knitwear product development process, and a summary of the body of knowledge that exists for the evaluation, learning and use of computer aided design.

2.1 Introduction to Integral Knitting

The term integral knitting indicates that the “shape [of the garment] is generated in the round during knitting, leaving little or no seam” (Brackenbury, 1992, p. 7). Integral knitting “minimizes or eliminates some or all of the labor-intensive processes of cutting and sewing, shaving off the production cycle as well as cost” (Brackenbury, 1992, p. 18). The process of integral knitting “minimizes yarn consumption, yields higher productivity, and results in garments with no bulky or irritating stitches and seams”; which is why integral knitting is often used in apparel products (Brackenbury, 1992, p. 18). Some examples of garments that have been integrally knitted are bras, sportswear, hosiery, and intimate apparel (Zheng, Yu, & Fan, 2009; Zargani, 2006; Keiser & Garner, 2008; Lloyd, 2007). This technology can be found in the medical textile field ranging from medical apparel applications such as compression socks to arterial substitutes that are seamless knit Dacron® tubes (McCurry, 2010; Debakery, Cooley, Crawford, & Morris, 2008). There are two different types of garments that are considered integrally knitted items: fully fashioned or complete garments. The machines that are capable of knitting complete garments are also capable of knitting fully fashioned items; however, machines designed for fully fashioned
knits are not typically capable of producing complete garments (Shima Seiki, 2010; Stoll, 2010).

The technology that is used for integral knitting is a combination of an electronic flat V-bed knitting machine and the CAD/CAM system that accompanies the machinery. The product that is to be knitted is designed on the CAD system, then programmed and translated to the knitting machine through the CAM system, and is finally knit on the electronic flat V-bed (Lam & Zhou, 2009). The CAD/CAM technology requires that the user understand a variety of knowledge bases that pertain to all aspects of integral knitting such as fiber, yarn, loop length, knit structure, silhouette, size, fashioning, and machine programming.

2.1.1 Flat V-bed Knitting Machines for Integral Knitting

Spencer stated in 2004 that “of all knitting machines, the modern electronic V-bed flat machine, with its comprehensive patterning and garment shaping facilities, offers the greatest challenges as well as the greatest opportunities for the application of a CAD/CAM system” (section 12.7). V-bed knitting machines have evolved from hand flat V-bed knitting machines to electronically controlled machines. The majority of these machines are “gauged on the English system (E) of needles per inch (npi)” which most often have standard gauges of 5, 7, and 10; finer gauges have become available with new technology (Spencer, 2004, section 18.3; Mills, 1965). The length of the knitting bed for integral knits is often 72 inches (Spencer, 2004).

There are two major electronic flat V-bed knitting machine manufacturers for integral knits: Shima Seiki and Stoll. Shima Seiki is a Japanese-based machine manufacturer, with a North American office in Monroe Township, New Jersey, that began in 1960 manufacturing
gloves and eventually transitioned into integral knitting (Shima Seiki, 2010). The latest electronic flat V-bed knitting machine, the MACH2X, is a complete garment knitting machine with 4 needle beds. It is capable of reaching a speed of 1.6 meters per second; this machine also can be manufactured at as fine as a gauge as 18E (Shima Seiki, 2010; Rodie, 2009).

Stoll is based in Germany with a North American office in New York, New York. Unlike Shima Seiki, Stoll started out making hand flat V-bed knitting machines which soon evolved into the electronic flat V-bed knitting machine (Stoll, 2010). The newest machines that Stoll produces are the CMS generation machines; these machines operate at higher speeds and have multi gauge functions, but the finest gauge machine produced is 16E (Stoll, 2010; Rodie, 2009). The complete garment machine of this family, the “CMS 730 S knit&wear” is only offered in gauges E 3, 5.2, and 9 (Stoll, 2010). Both companies provide a variety of different machines for different end uses such as gloves, socks, medical textiles, or garments.

2.1.2 Knitting Technology

The majority of knitted apparel is produced on either circular or flatbed knitting machines (Collier & Tortora, 2001, p. 329). The terms flat and circular refer to the needle bed configuration; needle beds in flatbed machines are arranged in a horizontal row, while a circular bed machine has one or two sets of needles arranged in a continuous circle. Flatbed knitting machines can knit a flat piece of fabric as well as a tube. The fabric that is knit on a circular machine is produced as a large tube, which is often split open to be used as yardage (Collier & Tortora, 2001). While there are four types of flatbed knitting machines (straight
bed, racecourse, single and V-Bed), V-bed knitting machines are by far the most commonly used. V-beds typically have two needle beds in the shape of an upside down V as seen in figure 2; however, there are newer V-bed machines that have up to four needle beds, such as Shima Seiki’s MACH2X (Spencer, 2004; Collier & Tortora, 2001; Shima Seiki, 2010).

When determining whether to use a circular or V-bed knitting machine, the product developer must consider production time, cost, and shaping capabilities. Generally, circular machines are more productive than V-bed machines due to the continuous circular motion of the yarn feed as compared to the back and forth traversing of the yarn carriers on a flat V-bed machine. In addition, circular machines typically have 36-48 yarn carriers in contrast to the one to eight yarn carriers on a V-bed machine. Both, the motion of the yarn feed and the
increased number of yarn carriers, contribute to the increased productivity of circular knitting machines. However, when comparing the ability to shape a knit product during the fabric formation process, V-bed machines are superior to circular ones. In order to understand why V-bed knitting machines have greater shaping capability, it is important to comprehend how a knit product can be shaped during fabric formation.

2.1.3 Shaping Capabilities

There are three different options for shaping during knit formation: “varying the number of needles in action in the knitting width, changing the knitting construction, and altering the stitch length” (Spencer, 2004, section 16.4).

“Varying the number of needles in action in the knitting width” is often referred to in the apparel and textile industry as “fashioning” and results in the highest degree of shaping (Spencer, 2004, section 16.4). Wale fashioning is the most common type of fashioning performed on an electronic flat V-bed knitting machine (Spencer, 2004). One or more loops may be fashioned at the selvedge of the item being knit in order to create a specific shape (Brackenbury, 1992). Fashioning comprises two types of movements: narrowing and widening (Brackenbury, 1992; Spencer, 2004; Mills, 1965). In widening, the loops are transferred outward and will leave a small hole in the garment as a result if the fabric is not “filled in” by the addition of a new stitch (Spencer, 2004, section 16.4.1). Narrowing requires that a loop (or loops) be transferred inward, shortening the number of wales in a given course (Spencer, 2004; Brackenbury, 1992). Figure 3 depicts these different types of fashioning stitches/movements. Narrowing and widening are done through transferring stitches within a specified course. This method is optimal on an electronic flat V-bed knitting machine.
because the machinery is able to transfer the stitches between the two needle beds and change the position of the stitches without the aid of the technician. In order for widening or narrowing to occur during the transfer process, one of the needle beds must rack, or shift position horizontally, in relation to the other needle bed. Once a needle bed racks over (usually from one to four needles), the stitch being transferred also moves position. This type of stitch transference is typically performed on a V-bed machine, although this method of shaping can also be accomplished on a cylinder and dial circular knitting machine with an oscillatory knitting system. However, the oscillating circular motion and transfer of stitches between the needle beds is a “much slower and more complicated process” than traditional circular knitting (Spencer, 2004, section 16.4.5); therefore, the vast majority of shaping during knit formation is performed on a V-bed machine.
The second most common way of knitting to shape is changing the stitch structure (Spencer, 2004). This method is faster than fashioning because it does not require any transfer stitches (Spencer, 2004); however, “it can only be used for a few definite step-changes of shape rather than the graduated shaping technique of fashioning” (Spencer, 2004, section 16.4.6). Shaping by changing the stitch structure does not add or subtract needles while knitting, but instead uses holding stitches, changes the type of stitch being used, or alters the stitches’ length. For example, a method of holding stitches, also known as flechage, can be used to simulate a dart. Holding stitches “involves holding the loops at the edge of the knitting and reducing in stages the length of the course being knit” and is mostly used for

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Figure 3. (a) Single needles narrowing; (b) Single needle widening; (c) Single needles widening and then filled in with a new stitch; source: Brackenbury, 1992, p.64.
“set-in sleeve heads and shoulder sloped” apparel items (Brackenbury, 1992, p. 62). This method is performed on a flat V-bed knitting machine and helps to eliminate any need for cutting (Brackenbury, 1992). One example of shaping by changing the stitch structure is going from a plain jersey knit to a rib knit while keeping the same stitch length; the change in knit structure will result in a width-wise decrease where the rib stitch is placed, as seen in figure 4. This sort of change in stitch type can occur anywhere on the garment (Brackenbury, 1992).

Changing the stitch length is yet another way to shape during the knit formation process. The stitch length can be changed on either a circular or flatbed knitting machine (Spencer, 2004). Because one does not need to change the stitch type when shaping this way, there is less variation in the uniformity of stitches in the knitted piece.
2.2 Knitting Development

Knitting is the second most widely used method of creating textiles and one of the fastest growing markets in the textile industry (Spencer, 2004; Collier & Tortora, 2001). Knit fabrics are formed by interconnecting loops of yarn (Collier & Epps, 1999). The interlooping can be formed in the horizontal or vertical direction; the two direction-oriented knitting types are referred to as weft and warp knits, respectively (Collier & Tortora, 2001). Of the two different types of knits, “weft knitting is the more diverse, widely spread and larger of the two sectors, and accounts for approximately one quarter of the total yardage of apparel fabric, compared with about one sixth for warp knitting” (Spencer, 2004, section 6.2.1). Collier and Epps (1999) state that “regardless of the type of knit, the lengthwise rows of loops in knitted fabrics are called wales, while the crosswise rows are called courses” (p. 86).
The dimensions of knit products are often calculated by counting the number of courses and wales.

Knits are highly elastic and conducive to shaping due to their unique interlooping structure (Collier & Epps, 1999; Spencer, 2001; Glock & Kunz, 2005). This characteristic has made knitted fabric a popular selection for a variety of textile products, such as those used for medical, automotive, and apparel applications.

The knitted apparel sector can be divided into four parts: “knitted outer wear, knitted yard goods, knitted hosiery, and knitted underwear” (Collier & Tortora, 2001, p. 327). Although all these categories have variations in their production processes, most apparel items follow a similar line of product development. The scope of this study focuses on the usability of software developed primarily for weft knitted apparel; therefore, it is important to understand the production and design as it relates to weft knitted garments.

2.3 Integral Knit Product Development

The model in figure 5 shows that the CAD/CAM system for integral knitting incorporates all steps of product development, from the inception of the garment design through the retail promotion. These steps include: planning, design, patterning, knit programming, virtual sampling, production, and sales promotion. Figure 5 also further demonstrates that it is not only the garment designer who is meant to benefit from using the CAD/CAM system for integral knitting; all roles that are incorporated into the product development of a knit product can benefit from using the system. Spencer (2004) states that “of all knitting machines, the modern electronic V-bed flat machine, with its comprehensive patterning and garment shaping facilities, offers the greatest challenges as well as the greatest
opportunities for the application of a CAD/CAM system” (section 12.7). The scope of the applications of the CAD/CAM system for integral knitting implies that there are a variety of knowledge areas a user must understand in order to become an expert on the system.

Figure 5. Model of integral knitting CAD/CAM features; source: Shima Seiki, 2010.

2.3.1 CAD for Integral Knitting

The Columbia Electronic Encyclopedia (2009) defines computer-aided design (CAD), as a "form of automation that helps designers prepare drawings, specifications, part lists, and other design-related elements using special graphics- and calculations-intensive computer programs". Unlike most industries that use CAD systems, the textile and apparel industry uses CAD for apparel design not only to engineer a product to be functional, but also to be
aesthetically pleasing (Hardarker & Fozzard, 1995). CAD for apparel design was introduced to the textile and apparel industry, like many other industries, with productivity in mind (Hardarker & Fozzard, 1995). CAD software for apparel design “maximizes designer creativity and speeds design and marketing in numerous ways” (Brown & Rice, 1998, p.72). For example, creative drawings of the garment silhouette can be stored in digital format and revised based on current trends, rather than having to create new hand drawn sketches each time a product is developed. The CAD programs for apparel design now offer a wide variety of functions, such as digital design, patternmaking, and a production development calendar (Keiser & Garner, 2008; Brown & Rice, 1998). CAD software has also been developed for knit textiles, which helps to assist in the design of knit structures. Although knit textile design and apparel silhouette design are most often performed by people in different roles with different skill sets and responsibilities, the CAD system for integral knitting incorporates these two design aspects of a garment, thus enabling one designer to perform both tasks. By using a computer for design ideation and specification depictions rather than creating each design from scratch by hand, the time to market is reduced (Hardaker & Fozzard, 1995).

Within integral knitting, the CAD and CAM systems are dependent on one another; the CAD system is used for design creation (all aspects of the knit product including both knit structure and garment development) and to specify the actions of the CAM; the CAM system will not drive the machine if the CAD file is not correct. A visual example of this relationship is depicted figure 5 at the “Knit Programming” tier. The actions within the “Knit Programming” tier, such as yarn carrier settings (which yarn carrier will be used to knit) and
package development (pattern development), help to program the knit design and also save information, such as the machine set-up requirements, according to the product specifications. This aspect of the process would be considered part of CAM because it focuses on the actions of the electronic V-bed knitting machine; although this process is also essential to the CAD system to be able to correctly simulate and/or check to see if the pattern would run. Clearly, because CAD and CAM are intertwined, the operator of an integral knit system must have a sufficient knowledge base in order to effectively operate both parts of the system. In other words, the operator must have a level of proficiency in both design and production, as it is difficult to define the actions of this particular integral knit system as solely CAD or CAM (Jerrard, 1976).

The CAD/CAM systems for integral knitting comprise two different parts that work in unison: software CAD and machinery CAM. These two parts are used to prepare the knit design and to drive the knitting machine. CAD is “any computer program that includes a graphic interface and can be used for designing, creating, and modifying,” whereas CAM mostly encompasses analysis, optimization, and evaluation of the new product (Garcia, Quiros, Santos, & Penin, 2005, p. 764). In order to understand the role of CAD in an integral knit design, it is important for the reader to grasp the product development workflow and see in which part of the design process CAD/CAM contributes. The CAD software comes installed on the computer system that is used in unison with the knitting machinery (Shima Seiki, 2010; Stoll, 2010; Spencer, 2004). An integrally knitted garment can be designed completely on the CAD/CAM system that accompanies the knitting machine; see figure 5 for a model of the system’s function.
2.3.2 Fully Fashioned

Fully fashioned garments have “trimmings, pockets, buttonholes and other accessories [that] are directly knitted in the fully fashioned produced panels” (Peterson, Larsson, & Rudrajeet, 2009, p. 2). Brown and Rice (1998) state that:

“Each part of a full-fashioned knit garment is knitted to the desired size and shape, not cut from a large piece of fabric. The shaped pieces are sewn together for an accurately sized and shaped garment that maintains its shape and does not twist” (p. 111).

In addition to being sewn, the fully fashioned garment pieces can also be linked. These garments are shaped by transferring loops, which results in courses being added to or subtracted from the garment; the addition or subtraction of loops is done through increasing or decreasing the number of needles one or both ends of the needle bed while the garment is being knitted without changing the type of stitch; the technique creates widening or narrowing in the knitted product as seen in figure 3 (Collier & Tortora, 2001; Mills, 1965; Brown & Rice, 1998). These transfers create stitches known as fashion marks, as seen in figure 6 (Collier & Tortora, 2001, p. 346; Mills, 1965; Brown & Rice, 1998). Fully fashioned garments are designed and created piece by piece, in separate shaped panels. The designer is able to see each pattern piece individually and put different knit structures or designs on each pattern piece.
Figure 6. The fashion marks can be seen on the bottom of the armscye, right next to the armhole seam.

2.3.3 Complete Garment

In contrast to a fully fashioned garment, a complete garment is created by knitting three tubes – one for each of the arms and a third for the body when creating a sweater – and then joining the tubes at the base of the armhole. Upon leaving the knitting machine, no assembly or seaming is required (Kanakaraj & Ramachandran, 2010; Shima Seiki, 2010; Stoll, 2010). The tubes are created by knitting on both the front and back bed and then using a transfer stitch to attach both courses at the sides; figure 7b shows a representation for this process (Kanakaraj & Ramachandran, 2010). The machines used to make complete garments
not only have the ability to create tubes, but are also able to merge these tubes, such as at the top of a sweater, as shown in figures 7. According to Specner (2004):

“The key concept of [whole garment] [also known as a complete garment] knitting is the ability to knit seamless body and sleeve tubes of virtually any type of plain, rib or purl construction, plus the ability to increase or decrease the sizes of the tubes and to move or merge them together as and when required during the garment knitting sequence.” (section 19.16).

Like the fully fashioned garments, complete garments also use transfer stitches to widen and narrow the shape of the garment while it is being knit, which often creates fashion marks, as seen in figure 8 (Spencer, 2004; Kanakaraj & Ramachandran, 2010). There is often less design flexibility in complete garment design when compared to fully fashioned knits. One reason for less design flexibility in complete garments is that the product developer is unable to put any knit structures at the places where the tubes are knit together to form a garment. In addition, to create color effects such as striping, intarsia or jacquard, additional carriers are needed for each of the three garment components. Whether it is a fully fashioned garment or a complete garment, in order to be able to knit on the electronic flat V-bed, one must design and program the pattern on a CAD system (Spencer, 2004).
Figure 7 a-d. Complete garment: “(a) breakdown of garment components; (b) loop diagram of tubes; (c) finished garments; (d) disposition of garment parts on V-bed flat knitting machine.” source: Brackenbury, 1992, p. 85.
2.3.4 Production Components

In the production process for integral knit garments, a designer (or CAD/CAM user) must complete four main steps in order to produce a final knit product. These steps include silhouette development, knit structure development, simulation, and programming; figure 5 shows a more in depth process for developing a knitwear product. The more traditional production process for knitted items, without the aid of the computer, included silhouette development, knit structure development, a series of trials in order to assess the correct garment parameters, and production (Keiser & Garner, 2008). This process took substantially more time to complete. The extended amount of time contributed to the traditional process of knit product development, without the use of CAD, was because the process was manual. In
addition, prototypes had to be knit in a production setting, rather than simulated, which caused a time extension in product development.

2.3.4.1 Silhouette Development

All aspects of the product development process are important to the success of a garment, but this research must investigate the design process of the knitted garment, due to the usage of CAD for apparel design that has permeated this sector of the product development cycle. The design development process is directed by “decisions about shape, silhouette, and style” (Brown & Rice, 1998, p. 101). There are two different aspects of design for which the designer is responsible: creative design and technical design (Glock & Kunz, 2005). During the creative design process, the aesthetics of the garment are planned, such as the color combination, the textiles to be used, silhouette, and knit design (Glock & Kunz, 2005; Keiser & Garner, 2008). These decisions about the garment are communicated through two-dimensional sketches, which are known as fashion figures and flat sketches; see figure 9 (Glock & Kunz, 2001; Stipelman, 2005).
Figure 9. Example of a technical flat sketch of a sweater and a fashion figure.

The technical design process encompasses developing fit standards, defining the materials to be used, and construction specifications (Keiser & Garner, 2008). This aspect of design often includes making the production pattern for the garment (Keiser & Garner, 2008; Glock & Kunz, 2001). In this step of the design process, cost sheets and specification sheets (such as in figure 10) are made in order to inform the manufacturer exactly how the garment should be produced (Glock & Kunz, 2001). The technical aspect of design was once only done by hand, much like creative design, but it is now also accomplished with CAD for apparel design (Glock & Kunz, 2001, p.189). This change in practice is important to the development of the CAD/CAM system for integral knitting because it combines both creative and technical design into one process. Such a combination helps the user design the knit garment and program the pattern to be transferred to knit on the knitting machine.
The CAD software for apparel design must be able to provide a sufficient amount of virtual design space where the designer can test out ideas in the conceptual phase in order to accommodate the design process. Technology has infiltrated both the design side of the textile industry and the machines that produce the garments. The job of a CAD system for apparel design users is to create or modify an existing product and convey a new concept to fellow designers, technicians, and all others who help to create the final product. All designers must first sketch a drawing of the final product – a garment for instance – and then make a specification sheet that defines all the details of the garment, such as the silhouette,
number of buttons, where the pocket is to be placed, etc. Traditionally, these aspects of design were done by hand (Thilmany, 2005). New technology continually permeates the textile and clothing industry, resulting in a variety of CAD programs on the market that are able to facilitate the design process with basic functions and provide a limited amount of virtual design space. What makes the CAD system for integral knitting designers so different is the unique dual role of the knitwear designer compared to that of a typical cut and sew clothing designer. Knitwear designers not only design the garment, but also must design the fabric that will be used in making the garment. The shape of the garment is dependent on the knit structure, so the fabric and garment are designed simultaneously. In integral knitting there is an increase in product design skills as compared to a traditional knit product design process. For example, in integral knitting the designer must understand and execute the textile design, garment design, and garment construction. The CAD system must be able to provide a continuous interface between all of these product development aspects and then translate the design attributes into machine code.

In a 1995 study by Hardaker and Fozzard, designers were introduced to CAD and then polled. The study investigated a small population of apparel pattern cutters and designers’ attitudes towards using a specific CAD system for apparel design and whether the participants’ age or previous computer experience influenced their attitudes (Hardarker & Fozzard, 1995). After learning CAD for apparel design, the designers stated that they felt this technology was a benefit to their own personal design skills and also was an aid to the design tasks at hand. According to the Columbia Electronic Encyclopedia (2009)
"Although CAD systems originally [were] merely automated drafting, they now usually include three-dimensional modeling and computer-simulated operation of the model. Rather than having to build prototypes and change components to determine the effects of tolerance ranges, engineers [and designers] can use computers to simulate operation to determine loads and stresses."

While this quote refers to CAD systems used in engineering, it is also relative to CAD systems for textile and apparel design because clothing, like most products in engineering, must be functional. Even if clothing is created for decorative or aesthetic purposes, it is still intended to cover the body or work as shaping and compression wear, which makes it a functional item. The knitwear designer is required to develop both an aesthetic and functional garment. The designer of integrally knitted items begins the product development process by designing the knit product on the software associated with the CAD system for integral knitting.

The CAD system allows the knitwear designer to complete the steps of product development virtually. These software programs integrate "yarn design, image design and knit loop simulation into one integrated CAD solution" (Lam & Zhou, 2009, p. 8). The software is not only able to aid in the creation of the garment and many of its vast garment silhouette and knit structure templates; it also can simulate each step of the design process: yarn choice, loop length, picking the garment silhouette, loop density, programming the pattern, and programming the machinery.

Designing the knit product includes choosing the shape of the garment, the shape of the neckline, the pitch of the armhole, and the sizing and proportions of the garment. When
considering complete garments, “emphasis is placed on perfecting the silhouette” (Lam & Zhou, 2009, p. 5). Until recently, “programming for such products have been considered complex and time-consuming, but with the Knit Paint program [which is part of the Shima Seiki CAD design system], this is performed very quickly and easily” (Lam & Zhou, 2009, p. 5). By using the CAD software for integral knitting, the designer is able to pick out a basic garment silhouette and then adjust certain aspects to fit the envisioned silhouette just by changing some measurements and using a few clicks of the mouse. As Hardaker and Fozzard (1995) point out in their research, in clothing and textile design there is more concern with the aesthetics of a final product than with the garment’s functionality as opposed to engineering (the other large majority that relies heavily on CAD systems for designing). The difference in a clothing designer’s concern for both aesthetics and functionality creates a need for specialized CAD software. For example, when designing clothing, the designer needs to be able to change different measurements of the garment. When the fashion silhouette or yarn type changes from season to season, the knit calculation must be reexamined, and often recalculated. However, instead of reinventing the garment silhouette each time, the CAD design software includes a design library of basic garment silhouettes which enables the designer to keep the same basic shape of a garment while also being able to change certain design aspects of the garment, such as knit structural designs. Having both garment silhouette and knit structure templates available to the designer of integral knit products reduces the time it takes to create a new knit product. Figure 11 depicts the silhouette design library that is offered as part of the Shima Seiki CAD design system.
An apparel designer can take various paths when creating a new garment; some examples include modifying a basic silhouette (either by adding trim or some other design), reshaping an existing silhouette, or creating a completely new design. Because garment designers can create new garments in various ways, it is important that most CAD software systems for integral knitting allow designers a choice either to load a basic garment design and alter it or design a completely new silhouette with no assistance.
2.3.4.2 Knit Structure

The flow of the CAD/CAM system for integral knitting dictates that the knitwear designer must design both the garment shape and the knit structure (Ward, J., personal interview, May 2010). The fabric design can be as simple as knitting the entire garment in a jersey knit, or as complicated as using knitting patterns that are strategically placed on the garment, such as cables or other decorative stitch combination. Although, with integral
knitting, specific structures are used for shape, such as when fashioning stitches are applied to the garment.

The CAD software for integral knitting is able to simplify the knit design process by offering a virtual design space where the designer is able to add and subtract ideas without having to physically knit a sample for each design idea. The majority of the textile design aspects of the CAD software for integral knitting rely on a variety of squares in different colors to represent different types of stitches. For example, the Shima Seiki software uses the color red to represent a basic front loop stitch (jersey). See figure 12 for an example of how the knit structure looks on the CAD system in the Shima Seiki software. To design a structure such as a cable without a library, the designer would have to compose the repeat stitch by stitch; however, with a stitch library, the designer is able to choose an already completed knit structure repeat.

The Shima Seiki software offers a variety of commonly used knit structure design patterns. Figure 13 shows how a cable would look on Shima Seiki’s CAD design software. Much like other CAD software, the designer is able to select certain aspects of the design and copy and paste the structure onto a different area of the design, making a replica of the structure. Editing designs is also much easier on the computer design system for integral knitting than designing by hand; the designer is allowed to undo, or erase, anything they have added to the design by just a click of the mouse. The software provides an extensive amount of pre-made (or preprogrammed) structures, referred to as the stitch library. The library enables designers unfamiliar with the integral knitting software to still be able to implement structural design features on the garment. It also helps both those that are skilled and
unskilled to save time by not having to create each structure stitch by stitch on the software. When the designer is finally satisfied with the design created on the CAD software for integral knitting, there is a simulation of the knit product available in order for the designer to view what the knitted product will look. The designer can also use the CAD program for integral knitting to check whether the pattern will run correctly on the knitting machine, another time-saving feature.

![Figure 12. Close-up image of a knit structure on the Shima Seiki CAD software; source: Shima Seiki CAD design system.](image1)

![Figure 13. Cable knit structure on a jersey background; source: Shima Seiki CAD design system.](image2)

### 2.3.4.3 Simulation

Another aspect of the CAD system for integral knitting is the two-dimensional and three-dimensional simulations of the knit product. Both Stoll and Shima Seiki have design systems that can display two-dimensional, three-dimensional, or both kinds of knit product simulation (Stoll, 2010; Shima Seiki, 2010). Spencer (2004) helps to describe the benefits of simulation when he states:
“Computer graphics provides a tool for the efficient creation and development of designs and overcomes tedious and repetitious aspects, enabling realistic representations of the knitted designs and garment shapes to be prepared, to be easily modified on the screen, and to be outputted as accurate, to-scale, coloured [sic], hard-copy prints. It provides a much quicker response to customer requests than is possible with traditional knit sampling techniques whilst postponing the expensive knitting operation until such requirements have been fully identified. Recognised [sic] standards for these systems are now becoming established so that there will be greater compatibility in the future and choice of system will be less dependent upon the preference for a particular make of knitting machine” (section 12.7).

Simulation helps the designer to see a visual prototype of the product and make alterations on the design system rather than have the product continuously sample knitted until it reaches satisfactory specifications for production, which wastes materials and time. The simulation, if sophisticated enough, is able to show the fit of the garment and whether it needs to be altered. These extra components have now been added to the traditional CAD systems and are essential to the integral knitting CAD systems. Often, if the designer is producing a garment on the electronic flat V-bed knitting machine with an emphasis on a fully-fashioned garment, the pattern on the CAD software looks completely different from the final knitted product. If no simulation were provided to the users of the CAD system for integral knitting, the process would consume a copious amount of time in order to get a correct final product because the garment would need to be designed and then knitted continuously until the correct proportions were achieved. Because of the ease that these CAD systems bring to
designing, it is reasonable to conclude that CAD will continue to be adopted to replace the traditional hand-drawn method.

A disadvantage of the CAD system for integral knitting is that it is only as productive as the user of the system is knowledgeable. If the user is untrained there is a probability that he or she will either be unable to complete the production of the knit product, or will be able to proceed through the steps in the CAD system, but unable to produce a knittable pattern. Another issue is that the virtual samples are not tangible; they do not allow the designer to feel the texture of the knit product until it has already been produced.

Two-dimensional simulations are used when creating the knitted stitch designs and loop simulations (Spencer, 2004, Lam & Zhou, 2009). Three-dimensional simulations are used when modeling the item on a virtual fit model. Stoll partnered with Eneas Informatica in order to create the three-dimensional simulation available on the CAD design system for integral knitting; whereas Shima Seiki developed its own form of 3D simulation (Lam & Zhou, 2009). Eneas Informatica has developed a “realistic cloth simulation system based on real fabric characteristics,” such as drape, texture, and distortion around the body; the simulation is called the Eneas 3D Stitcher (Eneas Informatica, 2010). The Eneas 3D Stitcher paired with the Eneas Shaper program “allows the creation of realistic knitted garments” and is specifically created for the integral and seamless knit industry (Eneas Informatica, 2010). See figures 14 and 15 for an example of Eneas Informaticas’s knitwear simulation.
The most recent addition to the design systems is the three dimensional fit model (Shima Seiki, 2010; Stoll, 2010; Spencer, 2004; Song, Wu, & Wei, 2005). This allows the designer to view what the garment would look like on a fit model once it was knit, as in
figures 16 and 17. A fit model is someone (or something, such as a mannequin) used to determine the standard of sizing of a garment for a particular company or institution. Because the virtual fit model is new relative to this technology, there is not much data available on the advantages and disadvantages of this aspect of simulation.

![Figure 16. “3D Modelist Software”; source: Shima Seiki, 2010.](image1)

![Figure 17. Detail of a simulation of an integrally knitted garment; source: Eneas Informatica, 2010.](image2)

### 2.3.4.4 Programming

The following action in the production process, called programming, is a critical step in the product development cycle. Programming allows the design of the garment to be transferred into the production criteria necessary to run the knitting machine. The technical aspect of the CAD/CAM system associated with integral knitting allows the designer to transform the knit design into knitting instructions for the knitting machine without using any programming language; the software automatically converts the pattern (Lam & Zhou, 2009). The technicality of programming the pattern becomes easier due to the templates of garments that the CAD system supplies for the user (Shima Seiki, 2010; Stoll, 2010). These supplemental patterns help to guide the designer and ensure that the pattern will be able to
run on the machine (Spencer, 2004). The CAD/CAM system for integral knitting allows the user to input the “machine type, gauge, stitch density, and other parameters,” therefore allowing the software to accurately calculate “the needles that should be in action in every course, including which needles should be decreased and which increased according to the shape of the product” (Song et al., 2005, p. 549). Where the pattern programming becomes the machine programming is not completely clear; both the pattern and machine programming must be accurately articulated in order to be able to successfully knit the design on the machinery. Each type of programming is combined automatically and must be saved onto a carrier, such as a floppy disk, USB drive, or other compatible device in order to be installed onto the knitting machine (Spencer, 2004).

2.4 Learning CAD/CAM

Learning how to use the CAD/CAM system for integral knitting is very different from learning traditional apparel design work methods such as hand drawing and sketching because the CAD/CAM system is interactive with users. Learning is defined “as a change in knowledge and skills that enables new and different kinds of performance” (Lovett & Greenhouse, 2000, p. 196). Design technology has been invented to help its users “work towards finding a solution to open-ended problems” (Sidawi & Mai, 2009, p. 270). As in most creative fields, learning CAD/CAM systems requires both motor and cognitive learning, especially for knitwear design (Hamade, Artail, & Jaber, 2005).

Cognitive learning is a common educational theory that is also applicable to the basis of learning a CAD/CAM system. Cognitive theory specifies “a fixed set of general mechanisms designed to explain learning and performance across a broad range of
situations” (Lovett & Greenhouse, 2000, p. 196). This theory explains how the brain processes information in general in order to learn new material and also enable the person learning the new material to apply it to other situations. There are five principles of learning that come from the cognitive theory. These principles are:

1. Students learn best what they practice and perform on their own.
2. Knowledge tends to be specific to the context in which it is learned.
3. Learning is more efficient when students receive real-time feedback on errors.
4. Learning involves integrating new knowledge with existing knowledge.
5. Learning becomes less efficient as the mental load students must carry increases.

(Lovett & Greenhouse, 2000, p. 196-197)

These principles can be applied to any kind of information being learned. When teaching and learning the CAD/CAM system for integral knitting, these five principles should be taken into account in order to maximize the information learned and minimize the time it takes to learn it. The first principle when learning a CAD/CAM system is how much time the student is allowed to privately use the technology to practice (Garcia, et al., 2005). Each person learns at a different rate; therefore, opportunities must be available outside of the allotted classroom time to allow greater access to the CAD/CAM system for students who require more hands-on experience. In a traditional academic environment, a student is typically able to learn a specific task during class time – not an entire computer system. Garcia et al. (2005) state that “the number of teaching hours dedicated to CAD at the university is insufficient to master these technologies or to allow a student to study more...
deeply those concepts that he did not clearly understand or to investigate that areas that remained unexplored” (p. 768).

The second principle explains that knowledge is specific to the environment in which it is learned. When concerning the CAD/CAM system for integral knitting, if a new user is taught how to design and develop a sweater on the system the user is then expected to eventually be able to produce an integral knit sweater without any assistance. It cannot be assumed that the new user will then be able to create a skirt because that knowledge is not specific to the context in which the new user learned how to design a garment on the CAD/CAM system.

When the new user is able to “receive real-time feedback on errors” learning the CAD/CAM system is more efficient. The third principle is a logical deduction because the new user is able to understand his/her errors and how to avoid making the same mistakes or how to remedy the errors once they have been created.

According to the fourth principle, learning new information relies on integrating existing information. This principle validates the importance of establishing the existing knowledge level of a CAD/CAM system for integral knitting user in order to assess the amount of new information that must be learned in order to effectively and efficiently use the CAD/CAM system for integral knitting. The fifth principle of cognitive theory is especially applicable to learning CAD because each type of computer aided design system is created differently; thus, the user cannot necessarily expect that what he/she has learned from one CAD system will be applicable to another CAD system. Theoretically, a new user may be forced to learn every aspect of a CAD system as new information.
Cognitive load theory, which is referred to in the fifth principle of cognitive theory, explains how an increase in mental load leads to an inefficient level for learning. Moreno (2004) explains that “cognitive theories of learning are based on the idea that learning occurs when learners actively construct a coherent knowledge representation by way of limited capacity working memory” (p. 101); when learning something new, the mind uses working memory, which is limited in each person (Moreno, 2004). The limited capacity of working memory is an important consideration when learning a new subject. If there is more knowledge to be learned than the user’s prior knowledge on the subject, there will be more working memory used in the learning process. Moreover, because working memory is limited, only a finite amount of information can be retained at one time (Marcus, Cooper, & Sweller, 1996). Considering the cognitive load theory, learning CAD should take place in a series of steps in order to limit the cognitive load on the new user, thereby staying within the capacity of working memory. “According to [cognitive load theory], when students have low-prior knowledge in the domain, cognitive load will be high because no schema is available to process the new information” (Moreno, 2004, p. 101). This will prevent the new user of the CAD system for integral knitting from being able to retain much new information at one time.

As Hamade, Artail, and Jaber (2005) point out, cognitive learning is more involved than motor skills learning because cognitive learning requires that the user of the CAD/CAM systems understand how the system works and how each command relates to the task, and the entire design process. Therefore, cognitive learning increases when technologically advanced systems such as the CAD/CAM system for integral knitting are used (as opposed to
the traditional hand drawing and sketching) due to the multiple functions one needs to perform in order to create a garment. A computer aided design system can be seen as a “discovery-based multimedia program” (Moreno, 2004, p. 100). According to the cognitive theory, the use of a “discovery-based multimedia” software program “promote[s] deep understanding by actively involving students in the learning task,” although the “limited capacity assumptions of cognitive load theory discourages the use of multimedia programs that overload the novice learner with too much new information and no guidance” (Moreno, 2004, p.100). Computer aided design systems are better able to engage a new learner and interact with a user. This participation promotes learning, but computer aided design systems need to avoid over stimulating the new user and thereby overloading him/her with new information.

Another aspect of learning the CAD/CAM system for integral knitting is the user’s ability to construct a schema, which “is defined as a cognitive construct that permits one to treat multiple elements of information as a single element categorized according to the manner in which it will be used” (Marcus, et al., 1996, p. 49). According to Marcus, Cooper, and Sweller (1996, p. 50), “information stored in long-term memory is stored in schematic form and, at least in part, learning involves schema acquisition”. A schema helps new users of the CAD/CAM system for integral knitting integrate existing knowledge and new knowledge. An example is how to open a new design with be similar on the majority of CAD systems; thus, creating a schema. The ability to form a versatile schema is derived from a person being involved in variations of a similar type of activity, such as using a variety of computer aided design software systems. If the user has already been trained on a
CAD/CAM system for textiles or apparel, then the user may have already constructed a schema for using a complex CAD/CAM system. For example, basic functions such as saving files, drawing straight lines and erasing mistakes may be similar from one CAD system to the next. A new user can apply this schema of basic CAD operations when learning how to operate the CAD/CAM system for integral knitting.

Motor skill learning is any learning involving hand-eye coordination; the user of the technology must practice on the CAD/CAM system in order for his/her motor skills to adapt to operating the systems efficiently and effectively by a series of repetitive movements such as clicking the same icon on the desk top in order to open a program (Hamade et al., 2005). This aspect of learning eventually translates into automation; once something is familiar, such as identifying a letter in the alphabet, the information is processed automatically by the user (Marcus et al., 1996). The more time a user spends on the CAD/CAM system for integral knitting, the more quickly automation is developed. Because this type of technology is just beginning to be widely adopted in the apparel and textile industry, it is difficult to identify the most accurate way to effectively teach both the cognitive and motor skills needed to accurately use the CAD/CAM system for integral knitting. This is partly due to the dichotomy present in every industry; there are two types of people learning how to use the CAD/CAM systems: the younger learners that have grown up using technology and the older learners that are being introduced to newer technology and started to use that technology later in life (Hardaker & Fozzard, 1995). By being able to previously create schemas through cognitive learning, the younger learners may be able to better apply previous situations to the new CAD system. They may therefore learn at a faster rate than older learners who have not
used as much computer technology and are hence unable to create as many versatile schemas to assist in learning new CAD systems.

Most users “require radically different combinations of skills to operate different computer systems effectively, from possessing high levels of manual dexterity and patience at one extreme, to the skills of a numerate typist at the other” (Jerrard, 1976, p. 240). One important consideration of using the CAD system for integral knitting is whether the system is convenient for the user to design a product and prepare it for production. CAD systems for integral knitting are “highly sophisticated expert systems which support programming by automatically generating knitting machine programs from symbolic representation”; therefore, to accurately use the software, the user must understand what each symbolic representation will translate to when transferred to the machinery (Eckert & Bez, 1999, p. 134). If for example, the user does not know what each stitch looks like and how it is knit, then the CAD symbol for a cable will become less useful. Before there was a CAD system to assist designers in creating knit structures, these knit textile designs had to be created by hand, the designer drew the path of the yarn around a series of dots. This method requires the designer to know how each structure will knit, whereas the CAD system for integral knitting assists the user greatly, offering a knit structure design library so the user need not understand the process the knitting machinery’s production process in great detail. Though the program allows the user to create knit structure patterns, these patterns may not translate when knitted and will not run correctly if the user of the CAD/CAM system is not familiar with the knitting machinery’s capabilities.
The usability of the CAD system is also affected when the software is not conducive to the process of knit design, which entails garment concept, garment design, knit structure design, technical design, and production (Keiser & Garner, 2008). This is especially true in the conception phase of the product when the designer needs virtual space for idea generation and to explore design possibilities (Eckert & Bez, 1999; Jerrard, 1976). The CAD software needs to “allow temporality, ambiguity, and inconsistency” for the sake of the creative process (Allwood & Kalén, 1994, p. 146).

Although some problematic characteristics of the software’s usability may be due to the CAD system for integral knitting itself, the ability to accurately produce a knit product rests on the software user and whether the user has had sufficient and accurate training on the system. Jerrard (1976) explains that “it is important for a designer to use and appreciate the system boundaries which may limit or extend activities” in order to successfully produce a garment (p. 245). The understanding of these boundaries can be “achieved with a specific training period and activity-related reference manuals” (Jerrard, 1976, p. 245). There are many noticeable differences between expert and novice user of a CAD system. Experts are “better able to retrieve and use relevant (and only relevant) background knowledge at times when it [is] needed in the design process” (Allwood & Kalén, 1994, p. 150). Because experts understand the process that the CAD system for integral knitting follows, they are better able to use a “wider repertoire of strategies” to utilize the software to its greatest potential (Allwood & Kalén, 1994, p. 150). In order to become an expert on the CAD system for integral knitting, one needs training, practice, time, and supplementary learning materials.
2.4.1 Learning Aspects

Learning the CAD/CAM system requires three aspects of cognitive knowledge in order for the user to be successful: “declarative command knowledge, specific procedural command knowledge and strategic (or metacognitive) knowledge” (Chester, 2007, p. 26).

According to Chester (2007), “declarative command knowledge is knowledge about the commands or algorithms that are available within [CAD]” (p. 26). The user is required to understand what he/she is designing and know the best sequence of commands to use to achieve the specified design (Lang, Ebert, Gabel, & Barash, 1991). Declarative knowledge involves how a specific command or an entire CAD system works. By obtaining more declarative knowledge, the user will be able to understand the reasoning behind each command and how the commands relate to one another. Some of this type of knowledge can be applied to various CAD systems. Certain aspects of the declarative knowledge of a CAD system may not be used on a day-to-day basis due to the fact that not every command is utilized equally; rarely used commands are more easily forgotten.

Chester (2007) states that “specific procedural command knowledge is knowledge that enables the operator to execute the necessary commands to, for example, mirror lines, copy objects” and various other commands within a CAD system (p. 27). As Lang et al. (1991) simplify the definition; procedural knowledge is “how to do things or the strategies which can be used to carry out a task” (p 257). This type of knowledge directly affects the motor skills and helps to carry out what is understood in declarative knowledge. Procedural knowledge varies more between CAD systems and may even vary between different versions of the same CAD system (Chester, 2007). This is the type of knowledge that is concentrated
on in step by step instructions, however, this knowledge changes due to version upgrades or different software being utilized and so the knowledge “becomes redundant and need[s] to be relearned” (Chester, 2007, p. 27). This requires the users of CAD to consistently be trained and retrained with each system upgrade.

Strategic knowledge, or metacognition, includes processes like planning, monitoring, or revising a design in a CAD system (Chester, 2007). Most current CAD software requires users to engage more in predicting how to use the software rather than using this type of knowledge (Chester, 2007). Yet, strategic knowledge is extremely important when revising a design in the CAD system. It helps the designer locate an issue with the previously designed garment and then correct the issue. Strategic knowledge helps one to later change a design by being able to change the strategy that was employed (Chester 2007).

“Most training programs for CAD systems are designed to convey declarative knowledge to the operator,” whereas manuals are more focused on procedural knowledge and how to carry out each command (Lang et al., 1991, p. 257). Declarative information is most often taught in college and technical school, and less time is spent on procedural knowledge (Lang et al., 1991).

2.5 Training

As with most technology, accurate and thorough training of the CAD/CAM system for integral knitting is essential to the success of both the users of the technology and the company investing in the integral knitting technology. It is usually assumed that the more money and time spent on training, the more proficient trainees will be. If the users of the CAD/CAM system do not have precise and comprehensive training, the time and money
spent on learning will be useless (Hamade et al., 2005). Thus the return on investment, on the machinery itself (including the CAD/CAM system), the employees hired to use the technology, and the employee training on the equipment paid for by the company will be minimal if there is no one in the company who can expertly use the equipment. Sayer, Wilson, and Challis (2006) write that the two most common ways to learn the CAD system for integral knitting is training provided through the integral knitting machine manufacturer or in an academic setting. Unfortunately, neither teaching method is without flaws.

2.5.1 Training through the Machine Manufacturer

In most cases when a client of the integral knitting machine’s manufacturer purchases a machine, that client is eligible for training provided by the manufacturer. Both Shima Seiki and Stoll provide training for the purchaser of the machinery either at the respective company’s facilities or at the customer’s home base. The training varies with each company who purchases the equipment; the training time can range from days to weeks (or even years) and can be one-on-one training or class-room-style training (Hamade et al., 2005). Stoll offers international classes in Germany on the electronic flat V-bed knitting machine, and also offers classes in hand V-bed knitting at their office in New York City (Stoll, 2010). Shima Seiki also offers international classes in Japan, and provides classes in their United States headquarters in New Jersey (Shima Seiki, 2010). Unfortunately, little has been published on the parameters of each company’s training methods. This study’s primary researcher took part in a series of training sessions from a Shima Seiki technician. The company suggests that new students complete a series of four week-long training sessions, alternating between training at the Shima Seiki United States office and the user’s home
base, in this case North Carolina State University. In this instance each of the four week-long training sessions were held at the university. The curriculum for each session was based on learning the basic functions of the CAD/CAM system and the knitting machine. Each student was responsible for learning both the designer’s and the technician’s role when operating the machinery. According to John Ward – trainer and technician from Shima Seiki – each training session does not have a specific curriculum because each electronic flat V-bed knitting machine owner is involved in different types of knit product productions (2010). Training can also occur for more than a four week session, depending on whether the owner of the electronic flat V-bed knitting machine purchases more sessions. The core of industrial/company training for integral knitting is that nothing is standardized. One reason for this may be that CAD/CAM integral knitting systems are newer technology; another may be that, as Mr. Ward stated, most companies do not participate in the exact same type of knit production.

2.5.2 Academic Setting

A prime example of learning integral knitting and the CAD/CAM system and the related machinery in the university classroom setting is Sayer, Wilson and Challis’s 2006 study and observation of their own students in the undergraduate “BSc Hons Textile Design and Design Management” program at The University of Manchester.

At The University of Manchester in England, the professors performed this study and observation of their students because they began to notice that the students were not transferring the knowledge they were taught in a lecture setting to the laboratory classes where the activities were more hands-on (Sayer et al., 2006). Transference is a common
problem with university classroom teaching and learning. If the professor does not directly correlate the information in the lecture to the hands-on activity the students will be performing later, there may be a lapse of knowledge. As Sayer et al. (2006) point out, the lapse is not always due to a professor’s inability to thoroughly explain a concept; often times, students cannot understand technical concepts when they are unable to see the equipment or all the inner workings as the equipment is being used. Sayer et al. (2006), found that when teaching “3D seamless knitwear construction, an element of active hands-on learning is essential, and that a traditional lecture-based approach is not the best way to enable students to visualize three dimensional concepts” (p. 160). The study done by these three professors (Sayer et al., 2006) provided positive feedback for their hypothesis; hands-on learning is the best method to understand how to use an electronic flat V-bed knitting machine.

This research did not uncover other publications about learning to use the electronic flat V-bed knitting machine in an academic setting, but there is information on learning CAD in general at the university level. The CAD system is not easy to learn and the CAD system for integral knitting, like any other field in the textile industry, must take into consideration the functionality of the garment and the aesthetic of the garment (Garcia et al., 2005; Eckert & Bez, 1999; Hardaker & Fozzard, 1995). In the learning environment, this means the professor must make sure the student’s final product is not only functional as a garment but also aesthetically pleasing. By having a clear teaching objective, the professor is better able to pinpoint the important aspects of teaching the CAD system of integral knitting (Garcia et al., 2005). Unlike the manufacturer training sessions, the academic setting most likely will have a set curriculum; for instance, each student may have to design and knit the same
garment. There are most often two methods of teaching at the university level when concerning CAD training: the teacher explains the operations of a specific CAD system and then the students carry out the tasks, or the teacher only explains and teaches the concept of computer-aided design (Garcia et al., 2005). The choice is dependent on whether the students are learning how to actually use the CAD system or only about what this system is capable of doing. Although teaching CAD explains aspects of the different portions of the technology, it is often up to the student to accurately understand and absorb the knowledge.

2.5.3 High Learning Curve

The rate at which a new user learns (or learns and forgets) is extremely important to teaching/learning the CAD/CAM system because “understanding and quantifying the learning and forgetting process” helps to better establish not only how long training needs to be, but also how to effectively train a new user (Hamade, Jaber, & Sikstrom, 2008, p. 151). The primary researcher did not uncover articles that specifically addressed the learning curve for the integral knitting CAD/CAM system; however the study done by Hamade, Jaber, and Sikstrom (2008) helps to highlight some key aspects of why CAD systems in general (whether for engineering, textiles, architecture, or other avenues) tend to have a high learning curve. When there is an increase of repetition, then performance among CAD users improves; furthermore, when there is an increase of the number of features in the CAD system, performance is hindered (Hamade et al., 2008). CAD is difficult to learn, “it not only requires computer skills but also mental capacity, spatial vision and physical coordination” (Garcia et al., 2005, p. 766). A majority of those that have been trained on a CAD system have a need for continuous training due to the fact that the primary training was difficult, so
the rate of forgetting has increased (Garcia et al., 2005). Garcia, Quiros, Santos, and Penin, (2005) state that learning CAD and learning a new language have similarities; in both instances a person may know what he/she wants to design but not know how to express this idea.

2.6 Summary

In summation, integral knitting is a multifaceted process. It requires that a user be able to accurately and effectively use the CAD/CAM system that works in unison with the electronic flat V-bed knitting machine. The CAD/CAM system is an essential component in all aspects of integral knit design for fully fashioned garments and complete garments. Because this system is such an important part of the integral knitting process, users must understand how to use the software correctly. A new user can either be trained by the machine manufacturer or in an academic setting. Whenever a novice is trained, there is still a high chance that he/she may not retain all the information or may need further training to accommodate the CAD system’s high learning curve. To define how to correctly teach or learn CAD, it is essential to understand what knowledge is needed. Then the optimum plan for learning the CAD/CAM system can be created for a particular user.
Chapter 3: Methodology

The following five sections present the methods used in this study: 1) Research Design; 2) Technology Used; 3) Stage 1: Development of the Evaluation Instrument; 4) Stage 2: Testing of the Evaluation Instrument; and 5) Stage 3: Validation of the Evaluation Instrument by Integral Knit Experts.

3.1 Research Design

The objective of the research was to create, pilot test, and validate an evaluation instrument. The evaluation instrument can be used to determine the knowledge base needed to effectively use the Shima Seiki SDS-One CAD/CAM system to produce an integral knit product.

The research consisted of three stages. Stage 1 used the Delphi Method; review of literature; informal interviews with field experts; and observation, training and practice of integral knitting to create a preliminary evaluation instrument. Stage 2 utilized a series of two pilot tests to refine and test the evaluation instrument. During Stage 2, the primary researcher administered the evaluation instrument to a small set of participants, refined the evaluation instrument, and then conducted a second pilot test with a larger group of participants for further refinement. Once the evaluation instrument was pilot tested twice, the research progressed to Stage 3 which consisted of validation by integral knitting experts. Additionally, the Delphi Method was used in Stage 3 to identify field experts who had extensive experience in integral knitting. The validation by integral knitting experts verified that the
findings in Stage 1 and Stage 2 were the most accurate methods of evaluating users of integral knitting technology.

While both quantitative (ex. number of years and hours per week using the CAD/CAM system) and qualitative data (ex. observational notes on the participants ability to answer knowledge testing questions and perform a task) were collected, the majority of this research consisted of qualitative methods.

The collection of qualitative data through observation and interviews was deemed necessary for this research. Integral knitting is not yet a widely used method, and there are very few users of this product development process. When a sample size is either too small or too difficult to locate, qualitative methods are often employed by researchers. Qualitative research is not required to show “cause-effect relationships among variables,” thus making it possible to gather important information without having to establish a relationship between variables (Glicken, 2003, p. 152). Further, qualitative methods allow the primary researcher to collect useful data in the form of words and opinions rather than numerical data. Additionally, the advantages of qualitative methods are that “data can be collected quickly,” the “richness of data,” and yielding “preliminary insights” (Hair, Wolfinbarger, Ortinau, & Bush 2008, p. 83).

3.2 Technology Used

The machinery used for this investigation included Shima Seiki’s SDS-One Design System (the CAD software) and the New SWG-V Wholegarment knitting machine. This technology was chosen because the primary researcher had continuous access to the equipment in the laboratory at North Carolina State University College of Textiles. By
standardizing testing equipment, the primary researcher reduced the occurrence of variation in the testing procedure. The New SWG-V has a bed length of 180 needles and is a seven (E) gauge machine, with the capability of producing both fully fashioned and complete garments. This knitting machine was used for preliminary research in areas such as yarn testing, loop length testing. Additionally, it provided the primary researcher with experience on a knitting machine that knits both fully fashioned and complete garments. Further, the SDS-One Design System was used by the participants in this study in order to program and design an integral knit sweater that could be knitted on the New SWG-V. Also, it should be noted that the primary researcher observed the study participants while they worked on the SDS-One Design System

3.3 Stage 1: Development of the Evaluation Instrument

In order to effectively develop the evaluation instrument, the primary researcher was required to first understand two broad concepts:

- What knowledge areas are needed throughout the integral knit product development process; and
- How are evaluation instruments for knit product design—or product design in general—developed and used.

The first critical step in developing the evaluation instrument was identification of the main knowledge areas needed to efficiently and effectively use the CAD/CAM system for integral knitting. The processes used for determining the knowledge areas were:
comprehensive literature review; extensive training; and hands-on experience using the system.

Training required the primary researcher to complete four (4) week-long, on-site, training sessions – totaling 120 hours – with the machine technician/trainer from Shima Seiki. By participating in these training sessions, the primary researcher was able to understand what skill sets are essential when learning the software. After training was complete, the primary researcher knit, designed, and produced different garment samples with a variety of yarns, in order to continue to learn the CAD/CAM system, as well as utilize the knowledge obtained during the training sessions. Five main knowledge areas became noticeable when creating a knit pattern and then knitting on the machinery. The knowledge areas were defined as:

- Yarn;
- Knit Structure;
- Garment Development;
- Fashioning; and
- Machine Programming

In addition to the above, and in an effort to determine the optimal evaluation method, the primary researcher also reviewed literature on evaluation methods and discussed these methods with experts in learning new technologies. The Delphi Method was employed to engage experts that could provide insight into creating the evaluation instrument for this research. The Delphi Method “may be characterized as a method for structuring a group communication process so that the process is effective in allowing a group of individuals, as
a whole, to deal with a complex problem” (Linstone & Turoff, p. 1975, section 1). The individuals who assisted with the development of the evaluation instrument had expertise in one or more of the following four areas: (1) teaching and learning; (2) teaching computer aided design for textiles; (3) knit technology; and (4) integral knitting product development. The panel of experts consisted of three professors from North Carolina State University College of Textiles; two professors from North Carolina State University (“NCSU”) with expertise in teaching and learning technology; and a machine trainer/technician from Shima Seiki. The integral knitting system trainer/technician from Shima Seiki was asked to join the panel because he had more than 10 years of experience in teaching new users on integral knitting technology.

Weekly meetings with the NCSU textile professors and the primary researcher were scheduled to allow for unstructured dialog about the content and format of the evaluation instrument. In addition, the primary researcher conducted phone interviews with two NCSU faculty members who were deemed experts in evaluating student’s ability to learn technology. Further, a phone interview was conducted with the integral knitting system trainer/technician from Shima Seiki in order to learn if he had a method for evaluating new trainees. The weekly meetings notes and interview results were compared with the review of the literature on both teaching and learning of CAD software, as well as the creation and administration of evaluation instruments for product development.

The literature included studies conducted by Hamade et al (2006), Sayer et al (2006), Garcia et al (2005), Allwood and Kalen (1994), and Hardaker and Fozzard (1995). These studies explored how to distribute a task to a specific population and then evaluate how
effectively each participant completed the task. The tasks ranged from completion of one
final product—such as an integral knit bag (Sayer et al, 2006)—to the completion of a
collection of products—such as a variety of 3D CAD shapes used in engineering (Hamade et
al, 2006). The studies conducted by Hamade et al, (2006), Sayer et al, (2006), and Hardaker
and Fozzard (1995) evaluated: how accurately the final product was reproduced in
comparison to a sample; the time it took to complete the task; and/or the amount of steps it
took for a participant to complete the production of the product. Additionally, Reeve and
Peerbhoy (2011) found that an evaluation instrument can be used to successfully assess
performance.

Generally, a researcher is able to either use a previously established evaluation
instrument or create his/her own. Creation might be advantageous because “a newly-created
instrument is tailored to the specifics of a study while an established instrument may not have
been developed to test the issues [the researcher has] in mind” (Glicken, 2003, p. 88).
Switzer, Wisniewski, Belle, Dew, and Shultz (1999) state that the advantages of generating a
new evaluation instrument are that the research is able to:

1. Conduct focus groups and reviews by experts to ensure that the content of the
   [evaluation instrument] is specific to [his/her] research goals
2. Control item wording and response categories, and
3. Establish the length of the [evaluation instrument] at the outset. (p. 406)

Based in part on the studies in the literature review, and by consultation with university
experts in CAD teaching and evaluation, the primary researcher determined that the
evaluation instrument should contain:
• Guidelines for assessing the skill level of the participant;
• A method for the participant to self-assess skill level;
• A procedure for completing a task wherein the primary researcher could observe the participant; and
• A method for the participant to self-assess skill level again after completion of the task.

3.3.1 Development of the Evaluation Instrument Components

Once the format for the evaluation instrument was established and the knowledge areas were defined, the primary researcher sought to develop the four components of the instrument: 1) a preliminary survey wherein the participant could self-assess his/her knowledge and skill level; 2) a direction manual to aid the participant during completion of a task; 3) a post survey for participant reassessment after task completion; and 4) a rubric for guiding the assessment of the skill level of the participant. Through discussions with both the Shima Seiki trainer and the NCSU textiles faculty experts, it was determined that the task to be completed would be the replication of an integral knit sweater. Participants were given a physical, full-size jersey knit sample of an epaulet, long-sleeved sweater to analyze, and were then asked to design and set-up the machine programming for the knit garment using the SDS-One Design System.

3.3.1.1 Preliminary Survey

The preliminary survey administered by the primary researcher collected information about the participant’s existing knowledge with self-rating questions and testing. The format
of the preliminary survey was guided by the following studies: Hamade, Artail, and Sikstrom (2007), Chester (2007), and Hardaker & Fozzard (1995). All of the preliminary surveys discussed in the studies gathered information about the user’s background (for example: job title, years of experience, frequency of use of the CAD system, training experience, and the participant’s attitude) to better understand how each participant differed. The information gathered in the studies was also used to gain insight into why the participant may have reacted in a certain way during the course of the study, and how that may have affected the outcome of the research (Hamade et al., 2006; Chester, 2007; Hardaker & Fozzard, 1995).

Similarly, the main objective of the preliminary survey in the present evaluation instrument was to gather information about the participant’s knowledge base; amount of training; previous use of CAD systems (both for apparel design and integral knitwear design); frequency of CAD systems usage; experience in knitwear production; and familiarity with integral knitting. Refer to Appendix A which includes the preliminary survey used in the evaluation instrument.

Like the preliminary surveys discussed in the Hardaker and Fozzard (1995) and Hamade, Artail, and Sikstrom (2007) studies, the present evaluation instrument included a section asking the participants to self-assess themselves using a series of rating scales. Additionally, the participants in both of the above studies were asked to assess their attitudes towards CAD software (Hardaker & Fozzard, 2006; Hamade et al., 2006). This assessment was also utilized in the preliminary survey employed in the present evaluation instrument.

The first type of question that was presented to the participant in the present preliminary survey was open-ended. Open-ended questions are defined by Glicken (2003) as
“questions on an instrument in which the answers are not pre-determined, and the subjects can write anything they believe to be relevant” (p. 269). The advantages of open-ended questions as listed by Robson (2002, p. 275-276), are they: are flexible; allow the researcher to “go into more depth or clear up any misunderstanding;” “enable testing of the limits of a respondent’s knowledge;” “encourage co-operation and rapport;” allow the primary researcher “to make a truer assessment of what the respondent really believes;” and can “produce unexpected or unanticipated answers.” Further, open-ended questions were primarily used in the present preliminary survey to ask the participant about his/her background and previous experiences, as figure 18 exemplifies. Because each participant has different background and experiences, the flexibility of the open-ended question was the primary reason that this type of question was utilized; however, an impediment exists in that it is hard to analyze the results and that “these questions require more thinking and effort on the part of the respondent” (Hair et al., 2008, p. 172). Due to these disadvantages, the open-ended questions were only used in the present survey when asking for the participant’s background and experience.

2. What is your job title?

Figure 18. Example of an open-ended question from the preliminary survey

Another type of question utilized on the preliminary survey was nominal multiple choice (Hair et al., 2008; Glicken, 2003). Because the majority of people are familiar with multiple choice questions, they are effective for gathering information (Bernard, 2000). On
the current survey, these questions had the participant provide information about the time (in years) and frequency (in hours and over the course of a year) spent on: CAD in general; knit development; integral knit CAD; yarn; knit structure; garment development; fashioning; and machine programming. This style of question was also used for testing questions in each of the five knowledge areas. Figure 19 displays one of the multiple choice questions used on the preliminary survey. Although the nominal scale is the “most basic and least powerful scale” in terms of analysis, these questions still enable the primary researcher to “categorize the responses into mutually exclusive subsets,” and also provided insight into the participants’ experiences and background. That insight, in turn, informs conclusions about how much time and frequency novice, intermediate, and expert users have spent with each category listed above (Hair et al., 2008, p. 149).
Three questions from the yarn knowledge area of the preliminary survey

2. How often are you responsible for the type of yarn to use when knitting?
   - Daily
   - Once or twice a week
   - Once a month
   - Four times a year
   - Once a year
   - Never

3. Please answer the average number of hours that you typically spend working with yarn in an average week. Please round up to the full hour.

4. Please answer how long you have been working with yarn in years. Please round up to the full year.

Figure 19. Three questions from the yarn knowledge area of the preliminary survey

A third type of question presented on the preliminary survey was an ordinal Likert scale. This question type was utilized because it helped to establish to what extent the participants agree or disagree with a series of statements, as seen in figure 20 (Hair et al., 2008; Glicken, 2003; Bernard, 2000). Like the nominal multiple choice questions, the ordinal Likert scale questions were also presented in each knowledge category. Additionally, there was a question pertaining to training and training methods. The use of this type of question was appropriate here because the present survey was self-administered online, and Likert scales “are best for research designs that use self-administered surveys, personal interviews, or online surveys,” (Hair et al., 2008, p. 155). Generally, a Likert scale helps one to self-assess by means of grading responses on a scale with a variety of values in either ascending or descending order (Gob, McCollin, & Ramalhoto, 2007). Further, Likert scales are usually
constructed of 5 to 7 points such as: strongly agree, agree, neutral, disagree, and strongly disagree (Gob et al., 2007; Bernard, 2000; Arnold, McCroskey, & Prichard, 1967; Jamieson, 2004). This study used a 5-point scale of strongly agree, agree, neutral, disagree, and strongly disagree for questions assessing the participant’s attitude. The Likert scale also helps the primary researcher gain insight into how the participant views not only the CAD/CAM system, but also the participant’s own knowledge concerning knitwear development and integral knitting. This type of question also has internal consistency, thereby making comparisons between the subjects simpler for the primary researcher to perform.

1. The following set of questions ask you to rate your knowledge of pattern development and programming.

<table>
<thead>
<tr>
<th>Please specify your level of agreement or disagreement with the following statements:</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. I understand what fashioning stitches are.</td>
</tr>
<tr>
<td>b. I understand what knitting efficiency is.</td>
</tr>
<tr>
<td>c. I understand how a fashioning sequence affects the knitting efficiency.</td>
</tr>
<tr>
<td>d. I understand how the silhouette affects the fashioning sequence.</td>
</tr>
<tr>
<td>e. I understand how to calculate a fashioning sequence.</td>
</tr>
<tr>
<td>f. I understand the difference between inside and outside fashioning.</td>
</tr>
<tr>
<td>g. I understand how to use widening or narrowing stitches to shape a garment.</td>
</tr>
</tbody>
</table>

Figure 20. Example of a Likert scale from the fashioning section of the preliminary survey

The last type of question that was used in the preliminary survey was the ratio rating scale, also known as a magnitude rating scale, which is a type of ordinal scale (Hair et al.,
2008; Bernard, 2000). Ratio rating scales enable the researcher both to identify the “absolute differences between each scale point” and “make absolute comparisons between the responses,” which in turn makes it the most accurate type of scale (Hair et al., 2008, p.150). Ratio rating scales are also more accurate than other rating scales because they have a “true zero point” (Bernard, 2000, p.43).

In the present study, the ratio question was used to determine the number of years of experience that the participant had in each specific area of knitwear development. The information gathered by this question helped to categorize the participants as novice, intermediate, or expert users insofar as the structure of the ratio scale allowed for “comparisons between levels” to be made, and also allowed for the mean, median, mode, and standard deviation can be calculated (Hair et al., 2008, p. 150-151).
3.3.1.2 Direction Manual for Completing a Task

During the study, it was important to have the participants use the CAD software for integral knitting in order to affirm that they had correctly self-assessed themselves in the preliminary survey. A direction manual—including a step-by-step sequence of how to create a jersey knit, epaulet, and long sleeve sweater—was given to each of the participants. Sales (1999, p. 268) states that dividing a learning tool into “small manageable units” helps to instill confidence in the participant and not make him/her feel overwhelmed. Taking this observation into account, the manual was split into the five knowledge areas that were established: yarn; knit structure; garment development; fashioning; and machine programming. Additionally, Marcus, Cooper, and Sweller (1996, p. 60) further qualify Sales’s (1999) statement by explaining that the “information is difficult to understand if multiple elements cannot be processed individually because they interact.” This observation would be applicable to the CAD system, as well, if the direction manual were not split up...
into logical parts. Also, pictures and diagrams help to make the text easier to understand, and can be used in lieu of the written instructions, thereby making the cognitive load lower and the information easier to remember and understand (Marcus et al., 1996). Because of this observation, a majority of the steps in the manual provided a picture illustrating the task that the participant was to perform.

The direction manual content was carefully worded to aid the participant in navigation through the CAD system. When developing the direction manual the primary researcher made sure the wording did not impart new knowledge to the participant, thus, allowing them to complete a task the participants would not normally be able to complete with their present skill set. After task completion, assessment of knowledge was collected through the post survey.

3.3.1.3 Post Survey

A post survey helps to measure the “dependent variables” (Bernard, 2000, p. 106). In the present research, the post survey was the reassessment of knowledge. The post survey was paired with the direction manual, and was constructed to have the participants self-assess again using two types of questions: self-rating and testing questions. For the self-rating questions, Likert and ordinal interval rating scales were employed because they allow the participant to choose to which extent he or she agrees or disagrees with a statement. Also, in an ordinal interval rating scale the participant is able to rate the knowledge he/she has. Thus, use of a combination of the two scales was ideal for the present research.

After interviewing professionals who teach technology, it was highly advised that the survey provide testing questions to verify that the participants were self-rating accurately
because “testing provides a relatively simple and inexpensive way to measure academic accountability” (Moore, 2001, p. 855). Tests are seen as “valid and reliable indicators of achievement and aptitude” (Ickes-Dunbar, 2005, p. 3). Because a Likert scale alone cannot verify whether a participant completely understands particular knowledge concerning integral knitting, testing questions were included in the survey to provide reliable answers to qualify the participant’s self-assessment. The testing questions were all multiple choice questions because this structure of questioning is “excellent at measuring recall of facts,” which in turn translates to the participant being able to recall only relevant information when performing a task as an expert would (Moore, 2001, p. 855). Each question allows the participant the choice of “I don’t know” in order to allow each participant to reveal if he/she does not know anything about a specific area of knowledge.

The post survey in the present research was designed to allow the participant to reassess his/her self-evaluation when concerning his/her knowledge base in reference to integral knitting, which has in turn helped the primary researcher to rank the participants as expert, intermediate, or novice users of the CAD/CAM system for integral knitting. A post survey also helps to “determine improvement” (Glicken, 2003, p. 165). Here the post survey determined the improvement of the participant’s self-assessment. Additionally, after each section in the direction manual was completed each participant completed the corresponding section in the post survey. Similar to the previously discussed research models, the questions asked the participant to assess him/herself in reference to the recently completed task (Hamade et al., 2006; Sayer et al., 2006; Garcia et al., 2005; Allwood & Kalen, 1994;
Hardaker & Fozzard, 1995). This helped the primary researcher to obtain information to correctly assess each participant.

3.3.1.4 Initial Rubric

The primary researcher in the current study created a rubric to help assess and identify users of the CAD/CAM system for integral knitting as novice, intermediate, or expert users. In the future, this will help determine the amount of training a new user needs. The rubric was created based on a literature review of rubric development, as well as use and analysis of rubrics that were created and used by the panel of experts in the current research. The rubric utilized in the present study was further refined after the pilot tests.

In general, rubrics are based upon “situation-specific criteria” in which there is a “scoring guide” that the participant is measured against (De La Paz, 2009, p. 134). Rubrics are also easily adaptable to almost any research objective; they are flexible assessment tools that allow the participant to be categorized differently in each knowledge base area (Montgomery, 2000). The measurement categories contained in a rubric help to define each participant’s level of knowledge (Knight, 2006). Further, rubrics are seen “as a form of authentic and objective assessment” (Knight, 2005, p. 45). This is why the rubric was an invaluable device for the present study.

The tool used to categorize and measure the participant’s skill level for this study was a three-level scale rubric describing criteria for novice, intermediate, and expert users. Once validated, the rubric could be used in the future evaluations of each participant’s user level by assessing: years of experience; frequency of use of the CAD/CAM system; number of testing questions answered correctly on post survey; number of steps completed in the direction
manual; and the number of times the participant needed assistance while using the direction manual. As previously discussed, the combination of these factors assisted the primary researcher in assessing the participant as novice, intermediate, or expert users.

In studies conducted by Garcia et al. (2005), Chester (2007), Hamade et al. (2006), Allwood & Kalen (1994), all of which guided this research, the majority of participants were novices. A novice is generally defined as a user that has some knowledge of the subject being studied, but not enough time and frequency spent on the CAD/CAM system to gain a noticeable amount of knowledge about all aspects of integral knitting (Garcia et al., 2005; Chester, 2007; Hamade et al., 2006; Allwood & Kalen, 1994). Contrastingly, expert users have the knowledge needed to effectively and efficiently use the CAD/CAM system for integral knitting, and also have spent an extensive amount of time and frequency spent using the CAD/CAM system for integral knitting. Falling between two extremes, the intermediate category allows for the participant to be placed at a level that has some knowledge but does not completely understand everything. An intermediate user generally has spent moderate amount of time and frequency using the CAD/CAM system for integral knitting. The intermediate category was important for accurate assessment of the participant’s skills. It is unreasonable to only have a novice and expert category because that implies the participant either has very minimal knowledge or complete knowledge of the subject.

The participants in the present study were assessed on their skill levels in integral knitting as a whole. The number of test questions and steps completed correctly varied among the knowledge areas. The last aspect of the participant’s user level was based on the number of times he/she needed assistance from the primary researcher while he/she was
going through the steps in the direction manual. For the purpose of this study, assistance includes clarifying directions, assisting the participant in choosing the correct steps in order to continue to assemble an integral knit sweater pattern, or any other concerns that the participant had while going through the direction manual in the evaluation instrument. The categorization of expert, intermediate, or novice user based on the number of times that the participant needed assistance was generated by the primary researcher through practical knowledge, as well as her own experience going from a novice to intermediate user (see Appendix D for rubric).

For example, an expert user may have needed assistance 0-5 times throughout in completion of the direction manual. Contrastingly, an intermediate user may have needed assistance 6-10 times, and a novice user may had needed assistance 11 or more times throughout all the steps in the direction manual. Although this does not indicate that if a participant did not need any assistance then the participant was assessed as an expert, a participant may not have asked for assistance even if he/she needed help.

**3.5 Stage 2: Observation and Testing of Pilot 1 and Pilot 2**

In order to demonstrate reliability and validity, the evaluation instrument created in Stage 1 was piloted. If the instrument has been neither reliable nor valid, it would not have been useful in providing accurate data to achieve the research objectives. The method of observation and pilot testing was standardized throughout the study in order to enhance reliability. Additionally, there were two pilot studies conducted. After the first pilot test the evaluation instrument was modified to better assess participants.
3.5.1 Population and Sample for Pilot 1

The first pilot study consisted of four graduate students from the College of Textiles at North Carolina State University. The participants were selected based on a convenience sample; all four of the participants who were selected for the first pilot had some knowledge of knit product development. Two of the participants were familiar with integral knitting and the associated CAD/CAM system and had received the same training as the primary researcher; these two participants were pre-classified as intermediate users. The other two participants had little to no knowledge of integral knitting and the associated CAD/CAM system, and thus were initially considered novice users. Participants were chosen with varying skill levels to better assess the effectiveness of the evaluation instrument.

3.5.2 Population and Sample for Pilot 2

The population for Pilot 2 was a larger and more diverse sample. A total of 39 people were asked to participate, and 17 people consented. The group of 17 participants consisted of the following: ten novice users, six intermediate users, and one expert user.

A convenience sampling was used in the present study. The justification for this was that: 1) participants had to be local; 2) participants needed to commit one hour to the evaluation procedure; and 3) the primary researcher and panel experts used in the Delphi Method determined that the participants had to have some background in textiles. The combination of these three factors dictated a small population and sample. Further, the primary researcher needed to personally observe and administer the evaluation instrument using the stationary integral knitting equipment and CAD/CAM system located at North Carolina State University. Thus, a local population and sample must be local. Additionally,
the sample population was drawn from those people who had taken part in some aspect of
knitwear development or had been educated in textiles and apparel. Because integral knitting
is not widely used in the textile and apparel industry, nor is it in one condensed location,
convenience sampling was the only logical way to obtain participants.

All of the studies that provided a basis for this research also used convenience
sampling (Hamade et al., 2006; Sayer et al., 2006; Garcia et al., 2005; Allwood & Kalen,
1994; Hardaker & Fozzard, 1995). Convenience sampling is often used in “exploratory
research” (Bernard, 2000, p. 178). As there are minimal studies done on teaching/learning
CAD systems—especially for integral knitting—and on the evaluation and categorization of
the user’s level of expertise of the CAD/CAM system for integral knitting, it is reasonable to
categorize this research as exploratory. Much like other convenience samplings, it was
anticipated that this chosen population will give “similar information [as if] a larger
population [had] been available,” or at minimum some insight into the research objective
(Glicken, 2003, p. 184).

The subjects asked to take part in testing the evaluation instrument for this study are
those who have studied or worked in knitwear design, production, or technology. Different
skill levels were tested in order to ensure that the evaluation instrument could accurately
assess each type of user. Training on the Shima Seiki SDS-One CAD/CAM system varied
among participants.

3.5.3 Solicitation of Participates for Pilot 1 and Pilot 2

The participants were solicited to participate in this research through electronic-mail
(e-mail). The e-mail addresses were obtained through the database maintained by the NCSU
College of Textiles. When the participant consented to contribute to the research, the primary researcher continued communication through e-mail to set up a time for the participant to come to the Digital Design Lab located in the NCSU College of Textiles to complete the pilot test. Please see the solicitation e-mail located in Appendix E.

3.5.4 Administration Procedures for Pilot 1 and Pilot 2

The evaluation was administered by the primary researcher for both Pilot 1 and Pilot 2. The primary researcher and the participant were the only ones present at this meeting to ensure the participant’s anonymity and to allow the participant to feel more comfortable asking questions.

Before each participant began the evaluation, the primary researcher explained that the participants should not guess on any part of the evaluation instrument and should only answer a question if he/she was completely sure it was the right answer. The participant was instructed that if he/she was not completely sure of the answer to input “I don’t know,” which is an option provided on the survey, or to leave the question blank. These parameters were set because the evaluation instrument was trying to assess what the participant already knew; guessing does not indicate that the participant understands why he/she chose a specific answer and therefore does not give an accurate assessment of the participant’s amount of knowledge.

The preliminary survey, which takes approximately 30 minutes to complete, was administered by the primary researcher using Survey Monkey® in a secure, private setting with only the participant and the principle investigator present. The survey was developed and administered in accordance with the Institutional Review Board for the Protection of
Human Subjects in Research (IRB). Therefore, while the survey participants’ names were entered into the survey; no identifiable information was used for any written reports or publications. Robson (2002, p. 202) states that “evaluation is intrinsically a very sensitive activity where there may be a risk or duty of revealing inadequacy,” either in the participants taking part in the evaluation or the subject matter used in the evaluation.” Allowing the participants to remain anonymous reduced any risk to the participant.

The University IRB reviewed the evaluation instrument to assure participants that taking part in this study would not harm them or their reputation. Following the preliminary survey, the direction manual and the accompanying post survey were administered by the researcher and required 30 to 45 minutes to complete.

After completing the preliminary survey, participants were then asked to complete the task of duplicating an integral knit sweater sample using the specialized software for integral knitting. While performing the task on the specialized software, participants were asked an additional set of survey questions in order for the participant to self-assess again on the post survey. The post survey also contained questions that test the participant’s skill level in all knowledge areas. Survey results were recorded within Survey Monkey which is password protected and SSL encrypted.

Once the participant completed the preliminary survey, direction manual, and a post survey, review and analysis of collected data were performed through the rubric. The participants were measured against a rubric to determine whether each participant was a novice, intermediate, or expert user. Both surveys were recorded through Survey Monkey, which is an online survey provider that is password protected and SSL encrypted, ensuring
that only the primary researcher has access to the responses provided. The names of the participants will not be published, which helps to keep the anonymity of the participants. The results of the surveys cannot be linked to the information the participants provided regarding their knowledge of user level of the CAD/CAM system for integral knitting.

3.5.5 Pilot 1

Pilot 1 for the preliminary survey, direction manual, and the post survey were employed in this study to evaluate whether the evaluation instrument would be effective at assessing the user’s level of expertise with the Shima Seiki SDS-One CAD/CAM system. Piloting an evaluation instrument verifies that the language of the surveys is clear and determines that the questions are able to produce results that could help make a conclusion as to the amount of knowledge one needs in order to be categorized as an expert, intermediate, or novice user of the CAD/CAM system (Glicken, 2003; Drummond, 1990). The pilot has tested the reliability and validity of all aspects of the evaluation instrument that were used for this study. After the concerns were altered, the participants in Pilot 2 tested the modified evaluation instrument in order to determine if there were any further corrections.

3.5.6 Pilot 2

The purpose of Pilot 2 was to ensure that the modification made to the evaluation instrument after Pilot 1 more effectively assessed the participants. Pilot 2 was conducted using the revised evaluation instrument that was improved after Pilot 1. The second pilot provided greater reliability and validity to the evaluation instrument. Further, Pilot 2 allowed the primary researcher to test the evaluation instrument on a larger variety of participants.
with varying levels of knowledge and skill, which in turn provided feedback as to whether
the evaluation instrument was able to correctly assess each type of user level. Due to the
limited number of participants, the primary researcher was unable to gather significant
statistical data.

3.6 Stage 3: Development of the Validation Procedure

To lend validity to the evaluation instrument, experts in both integral knitting and
teaching technology were consulted to review the evaluation instrument. The most common
method of providing validity to a newly developed evaluation instrument is peer review, or to
have “experts in the field, and subjects or patients from the population for whom the
instrument would be appropriate, review the instrument and provide critical evaluations of
the content” (Switzer et al., 1999, p. 403). The primary researcher asked experts that work
with and/or teach knitwear product development or CAD/CAM for textile and apparel for
insight into validating the evaluation instrument.

3.6.1 Population and Sample of Experts

In order to identify experts, the primary researcher contacted companies that
participate in integral knitting, professors at universities that teach integral knitting,
companies that produce integral knitting technology, professors at universities whose areas of
research concern teaching and learning CAD technology, and companies that produce CAD
software for textiles and apparel. Once the primary researcher contacted industry experts
identified in the panel defined by the Delphi Method, the primary researcher asked them if
they were familiar with any colleagues in their field of study that would be considered an
expert and willing to take part in this research. The type of sampling used for this research was a method called snowball sampling, “a nonprobability sampling method that involves the practice of identifying a set of initial prospective respondents who can, in turn, help in identifying people to be included in the study” (Hair et al, 2008, p. 354). This type of sampling was utilized because “the defined target population is small and unique” (Hair et al, 2008, p. 137).

Thirty four experts were solicited to participate in validating the research in this study; seven consented to participate. Those who took part in this study consisted of three experts in the training and use of the technology from two of the leading integral knitting machinery manufacturers; an expert in using the integral knit technology working in the apparel industry; a professor of knitwear design at Philadelphia University; and an expert in CAD for textiles and apparel from a software company. These experts helped to guide the primary researcher when validating the evaluation instrument.

3.6.2 Informal Interviews

The participants were initially solicited to participate through e-mail; however, following e-mail solicitation the participant received a phone call to set up an interview time. This approach may have varied if the primary researcher was unable to locate both an e-mail address and phone number for the intended participant. If only one of the two modes of contact could be located through the database at NCSU College of Textiles, on the internet, or from a colleague, then that was the only method used to converse with a participant. In addition, if the participant who was to validate the evaluation instrument was not located within the United States, the only method of contact was e-mail. When the participant
consented to contribute to the research, he/she was sent a survey through e-mail in order to prepare for the informal telephone interview with the primary researcher. The informal interviews were conducted in a private setting, over the telephone, with only the participant and the primary researcher present. The results were recorded for documentation and retained on a password-protected area of a computer to which only the primary researcher has access.

The questions pertained to: the identified knowledge areas related to the CAD/CAM system for integral knitting; defining an expert; and validation of the types of questions; and sequence of components encompassed in the evaluation instrument. The questions that were e-mailed to the experts can be found in Appendix F. The information has been documented as transcribed notes that are only available to the primary researcher.
Chapter 4: Results

The key result of this study was the development, pilot testing, and validation of an evaluation instrument that will be useful in the future for assessing the knowledge base needed to effectively and efficiently use the Shima Seiki SDS-One CAD/CAM system. The main results of this research were: 1) the determination of the five main knowledge areas needed for the effective use of the CAD/CAM system for integral knitting; 2) the development of an effective method of evaluating a user’s expertise in the five main knowledge areas; and 3) identification of future research and teaching initiatives that are needed for the successful adoption of integral knitting.

4.1 Stage 1: Results

By assessing the CAD/CAM system for integral knitting, the primary researcher was able to discover the main knowledge areas that are utilized when using this technology. These areas are: yarn; knit structure; garment development; fashioning; and machine programming. Uncovering the five main knowledge areas helps academia to identify the information that should be imparted to new users of integral knitting technology, as well as, the areas of textiles, apparel, and design that training materials should cover. Additionally, understanding what the knowledge bases are also helps companies choose the best employee to design knitwear when first implementing integral knit technology, by assessing the employee’s knowledge in each of the areas. Further, recognizing the five knowledge areas proves that integral knit technology requires a user to understand a variety of information in all different aspects of knitwear.
After identification, the five knowledge areas were then used to create the evaluation instrument. The evaluation instrument comprises: a rubric to grade the participant; a preliminary survey where the participant self-assessed; a direction manual for completing a task; and a post survey that allowed the participant to self-assess again and be tested in each knowledge area.

The original direction manual that was created provided great detail about each step in creating an integral knit sweater and the purpose behind each step. This direction manual was only used during Pilot 1; however, because it led participants to choose the correct answer to input in the CAD/CAM system as opposed to the participant using his/her own knowledge to complete the required task of creating an integral knit sweater. Additionally, this direction manual was detailed enough that in could be used in the future as training material to instruct new users on how to create an integral knit sweater on the Shima Seiki SDS-One CAD/CAM system.

In addition, this study uncovered that in order to properly analyze a participant’s knowledge the direction manual must require the participant to complete a task as opposed to simply follow directions. This finding indicates to future researchers that when creating a direction manual for an evaluation instrument there must be some ambiguity within the directions to allow the participant to make decisions that would in turn reveal his/her knowledge of the subject being evaluated.

4.1.1 Yarn and Knit Structure

The first two knowledge areas in integral knit product development – yarn and knit structure – are needed before the user begins to employ the CAD software for integral
knitting to design the knit pattern. Each time an integral knit product is set for development, the yarn type must be chosen. Also, the gauge of the yarn must be considered in terms of the gauge of the machine, as well as the yarn ply and fiber content. After selection of the yarn, the user must then choose the knit structure. Knitting efficiency and product quality are highly dependent on both the yarn type chosen and knit structure chosen. If the loops are too tight, they will have trouble transferring off the needle, thereby reducing knit efficiency. Contrastingly, if the loops are too loose they do not stay on the knitting needles. The optimal knit structure is determined based on evaluation of a knitted sample created through a loop routine. A loop routine is programmed through the CAM system and the user specifies the size of the loop length. The user can specify one loop length or a range of loop lengths; the user must observe the loop routine during knitting and then examine the loop routine sample after all finishing processes have been applied and then choose the optimal loop size based upon these observations.

4.1.2 Garment Development

The third knowledge area —and next step— in integral knit product development is garment development. At this point in the process, the user is able to visually choose the garment silhouette from a digital library contained within the Shima Seiki SDS-One design system. Figure 11 depicts the garment silhouette library for the Shima Seiki machine that enables the user to choose a basic predesigned silhouette, thereby making the entire garment development process less time consuming (Lam & Zhou, 2009). This time-saving feature also allows the user to pick what he/she wants to use without having to know the name of the type of silhouette or how it is constructed. During garment development, the user must
calculate the fabric density in order to determine sizing. This software also requires the user to understand how to accurately specify fabric density and input the number of courses and wales per one inch—or centimeter—into the software. By the user inputting the courses and wales, the software is able to compensate for the knit density.

4.1.3 Fashioning

During customization of the garment silhouette—the next step in the process—the user must understand the knit technology of fashioning. This part of the software allows the user to adjust the garment curves, number of fashioning stitches, type of fashioning stitch, and the length of the hem. The user can also choose to knit the garment in a jersey knit formation or rib knit formation. When choosing the garment curves, the user can change the shape of the arm, neck, arm curve, and shoulder curve of the garment. This is done by choosing from a list of predetermined curves shaped at different angles. The arm curve can be selected as a “J-curve” or an “S-curve”; the curve affects the amount of ease that can be employed around the curve of the elbow. Fashioning stitches can be altered by choosing the number of stitches transferred within one sequence—the number of stitches fashioning per course—and selecting whether they are considered inside or outside fashionings. Inside and outside fashioning stitches affect the aesthetics of the garment by making the fashioning stitches either more or less pronounced. Fashioning and shaping are two defining aspects of an integral knit garment.
4.1.4 Machine Programming

Machine programming is the final step—and knowledge area—in product development for integral knitting. During the machine programming step, the user inputs the production criteria, which in turn sets the: yarns in and out; location of carriers; number of carriers; loop length; yarn tension; fabric take-down tension; and machine knitting speed. Since the inception of the Shima Seiki CAD/CAM system, the company has added a new auto-processing feature within the software which encompasses the machine programming, thereby making this step a bit more user friendly. Additionally, the auto-processing features have enabled a less-than-expert user, such as a designer with little knowledge of machine programming, to assist in completing this area of integral knit product development (Ward, J., personal interview, July 12, 2010).

The machine programming section of the CAD/CAM system for integral knitting is different from the others in that there are fewer knitting aesthetic options and more concrete choices that must be made in order for the pattern to knit on the machine accurately. For example the user must input the carrier numbers to be used when making a knit product. Additionally, there are certain carriers that must be used for certain integral knit products, such as a complete garment sweater.

By determining and defining these knowledge areas, the primary researcher was able to more thoroughly understand the knowledge base needed to effectively and efficiently run the CAD/CAM system for integral knitting. To investigate whether the participants in this study had the knowledge base needed, it was pertinent to develop an accurate evaluation instrument.
4.2 Stage 2: Observation and Testing

The study consisted of two pilots that provided both reliability and validity to the evaluation instrument. The pilots were needed in order to verify that the language in the evaluation instrument was clear and to determine whether the questions being asked would produce results that could help to make a conclusion about the level of expertise of each participant.

The participants in the study first took the preliminary survey in order to self-assess their knowledge in each of the five knowledge areas. After this survey was complete, the participants were asked to use the direction manual in order to complete the task of duplicating an integral knit sweater sample. Once a section in the direction manual for completing a task was concluded, the participant was asked to complete the corresponding section in the post survey in order to have the opportunity to self-assess again, as well as answer testing questions in order to validate that the participant correctly self-assessed. Finally, the participants were assessed against a rubric and were categorized as novice, intermediate, or expert users.

This study found that the knowledge area concerning fashioning confused all but one of the participants. Therefore, the fashioning area is considered the least understood knowledge area. This study did not generate any information to conclude the reasoning behind this finding, although the primary researcher hypothesized that the participants may have had issues with the fashioning knowledge area because they may not have had enough exposure to integral knit technology.
4.2.1 Pilot 1

Although the sample size was small for Pilot 1, it did provide insight about the effectiveness of the evaluation instrument. Only two out of the four participants were able to complete the evaluation and only one of those two followed the step-by-step directions correctly. All four participants stated that the direction manual provided adequate assistance in explaining how to create a sweater using the Shima Seiki SDS-One CAD/CAM system. The participants stated that they found the direction manual helpful because it facilitated the designing of an integral knit sweater and provided both visual and hands-on learning. Unfortunately, the direction manual was not intended to provide a learning/training instrument, and therefore had to be modified to better evaluate the participants after the completion of Pilot 1 (see section 4.2.5 for modifications).

Even though the participants understood how an integral knit sweater could be created after completing the evaluation, they were still unclear as to the reasoning behind each of the steps in the direction manual. This is especially true for the steps that explain how to choose different types of curves in the fashioning section. For instance: the participants did not understand how the different curves affected not only the shape (silhouette) of the pattern, but how it also affected the knitting sequence of the integral knit sweater.

After observing the second and fourth participants, the primary researcher noticed that the participants went through the process of producing a garment on the CAD/CAM system and then referred back to the direction manual to make sure they followed each of the steps listed. When questioned about this, both participants indicated that it was easier to recall knowledge learned from previous training on the Shima Seiki SDS-One CAD/CAM
software than to go through the process step by step. As seen in the results listed in table 1, neither of the participants was able to correctly complete the task of producing an integral knit sweater.

A majority of the evaluation instrument was proven to be a reliable and valid way to collect data from the participants. Pilot 1 did reveal; however, that the diction in some of the questions needed to be rephrased in order to collect data that would correctly evaluate the participants. For example, one of the rating scale questions initially read: “Please rate your knowledge on the following areas of knit product development as it pertains to knitting on a scale from 1-6, with 1 being Very Unknowledgeable and 6 being Very Knowledgeable.” The question on the preliminary survey now reads: “Please rate your level of expertise on the following areas of knit product development as it pertains to knitting on a scale from 1-6, with 1 being Very Unknowledgeable and 6 being Very Knowledgeable”.

Similarly, the direction manual needed some further refinement due to the software skipping steps during some of the studies. As the direction manual told the participants exactly what choices to make in order to successfully produce the garment, the participants were not being tested on their knowledge or skills. The direction manual only tested whether the participants were able to follow directions and complete a task (please see the modifications made to the direction manual explained in section 4.2.5).

After the evaluation of Pilot 1, it became apparent that the surveys would be more effective if there were only self-rating questions on the preliminary survey and a combination of self-rating questions and testing questions on the post survey. By having testing questions only on the post survey as opposed to testing questions on both the preliminary and post
surveys (as tested in Pilot 1), the participant would understand how the testing questions were associated with integral knitting by having had the opportunity to use the CAD/CAM system for integral knitting. The necessary changes were made to the evaluation instrument.

Table 1 charts the results of the first pilot study.

Table 1. Pilot 1 results.

<table>
<thead>
<tr>
<th>Participants</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Have had experience with CAD</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Have had experience with integral knitting</td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Were able to complete the direction manual</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Followed every step in the direction manual</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

4.2.2 Modifications Made to Rubric after Pilot 1

Categorizing each participant in each of the five knowledge areas (yarn, knit structure, garment development, fashioning, and machine programming) as either a novice, intermediate, or expert user, as well as in integral knitting as a whole was the first modification made to the rubric after Pilot 1 was complete. By assessing each participant’s level of expertise in each knowledge area, the evaluation instrument was able to show a more complete view of each participant’s knowledge. Also, the modification revealed that
although a participant may be an expert in yarn and knit structure, such expertise does not necessarily transfer to integral knitting.

The expertise level associated with time and frequency spent using the CAD/CAM system for integral knitting was also modified to correlate with the information that the primary researcher gathered from informal interviews with industry professionals. According to two trainers and one expert user in integral knitting and the CAD/CAM system, an expert user should have about ten years’ experience with about 30-40 hours a week using the electronic flat V-bed knitting machine and the CAD/CAM system for integral knitting. One of the trainers for the CAD/CAM system for integral knitting commented that there are sometimes cases when a new user may be able to become an expert at a faster rate, depending on the rate of learning. An expert in using the integral knit technology, as well as an expert in teaching CAD for textiles and apparel agreed with this statement. The expert user of integral knitting and the associated CAD/CAM system also expressed that the opposite is also true: learning the CAD/CAM system for integral knitting may also take longer than 10 years if the user does not use the CAD/CAM system for 30-40 hours a week. This is because the system is extremely complex and requires reinforcement to maintain knowledge of how to use the system. Thus, the rate of learning must exceed the rate of forgetting. Table 2 displays the expertise levels when only considering the time and frequency on the CAD/CAM system for integral knitting. In future research, participants should not be asked how many times a year he/she uses the CAD/CAM system for integral knitting, but rather how many weeks within a year he/she uses the integral knit technology.
Table 2. Time and frequency on the CAD/CAM system for integral knitting for each level of user.

<table>
<thead>
<tr>
<th></th>
<th>Expert</th>
<th>Intermediate</th>
<th>Novice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Years of experience</td>
<td>10 or more</td>
<td>5-9</td>
<td>0-4</td>
</tr>
<tr>
<td>Frequency used during a year</td>
<td>Daily, once or twice a week</td>
<td>Once a month</td>
<td>Four times a year, once a year</td>
</tr>
<tr>
<td>Hours per week</td>
<td>30+</td>
<td>15-29</td>
<td>0-14</td>
</tr>
</tbody>
</table>

Following Pilot 1, the number of testing questions was changed on the evaluation instrument, and the rubric was also updated to reflect this alteration. Table 3 shows the number of test questions as well as and the number of steps that the participant must have completed in the direction manual in each knowledge area. The revised evaluation instrument asked a total of 25 test questions and asked the participants to complete 44 steps in the direction manual. In order to be considered an expert user, 17-25 test questions must have been answered correctly and 29-44 steps in the direction manual must have been correctly completed. For an intermediate user, 9-16 test questions must have been answered correctly, and between 15-28 steps in the direction manual must have been completed correctly. Lastly, a novice user only needed to answer 0-8 test questions correctly and have correctly completed 0-14 steps in the direction manual.
Table 3. Number of testing questions and steps to complete in each knowledge area.

<table>
<thead>
<tr>
<th></th>
<th>Yarn</th>
<th>Knit Structure</th>
<th>Garment Development</th>
<th>Fashioning</th>
<th>Machine Programming</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Testing Questions</td>
<td>7</td>
<td>2</td>
<td>6</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Number of Steps in the Direction Manual</td>
<td>2</td>
<td>2</td>
<td>10</td>
<td>12</td>
<td>18</td>
</tr>
</tbody>
</table>

In summary, the revised rubric component of the evaluation instrument following Pilot 1 assesses the participants in each knowledge area and in integral knitting as a whole, as opposed to only assessing the participants the latter. This was done by considering time in years of experience, frequency of use during a year, and frequency of weekly use of an integral knitting CAD/CAM system. In addition, the number of test questions answered correctly, steps that were able to be completed in the direction manual, and number of times the participant needed assistance during the evaluation for each knowledge area were considered when the participant’s user level expertise was assessed. In a sense, the rubric is composed of five smaller rubrics each focused in one knowledge area, with an added sixth aspect of the rubric considering the cumulative skill level in integral knitting as a whole.

The time and frequency criteria were also standardized throughout the entire rubric. The expert user was expected to have had ten or more years using the technology—at either a daily or bi-weekly basis—at 30 or more hours per week. Spending extensive amounts of time on the integral knit technology reinforces both cognitive and motor skills, whereas less time spent on the technology increases the rate of forgetting. This is why measures of frequency
and contact hours must be considered along with years of experience in assessing expertise level.

4.2.3 Modifications Made to Preliminary Survey after Pilot 1

The preliminary survey evaluated participants using both self-rating questions and testing questions. Through analysis of the results produced by the pilot study, the primary researcher became aware that some of the questions asked on the preliminary survey would be better answered if moved to the post survey. For example, the testing questions which required the participant to have more understanding after using the direction manual in combination with the CAD/CAM system for integral knitting were better placed in the post survey. When reviewing the survey answers from Pilot 1, the primary researcher concluded that the testing questions would be more effective if moved to the post survey because it was not a study requirement that the participant had previously used the CAD/CAM system for integral knitting. Therefore, many of the questions were misunderstood in Pilot 1 due to the participant having little awareness of the CAD/CAM system for integral knitting. Because it is essential to have testing questions to ensure that the participant is self-rating correctly, it was logical to move the testing questions to the post survey where the participant would have already had access to the CAD/CAM system for integral knitting by taking part in the evaluation instrument testing and using the direction manual. Other modifications were made to some of the self-rating questions on the preliminary survey where the participants were asked to self-rate their own expertise in specific areas of integral knitting. After modifications, the preliminary survey included only self-rating questions.
4.2.4 Modifications to Knowledge Rating Scale

Another issue arose when the primary researcher was examining the answers to Likert rating-scale questions. On the questions asking participants to self-rate about the amount of the knowledge they had, some participants answered “neutral,” which was given as the mid-point option. It was not understood by the primary researcher or the panel of experts engaged in the Delphi Method how one can have “neutral” knowledge. It was decided to change this type of question to an ordinal interval rating scale in order to get a more precise answer from the participants in this study.

Generally, an ordinal interval scale is employed in order to have the participant rate his/her level of expertise (Hair et al., 2008; Glicken, 2003). In an ordinal interval scale, the choices—and therefore answers the participants provide—“ranked and ordered” (Glicken, 2003, p. 194-195; Bernard, 2000). The mean, median, mode, and standard deviation are calculable (Hair et al., 2008), if the sample size is sufficiently large. Further, the ordinal interval scale in this study had participants rate their level of expertise on a scale from 1-6, with 1 being very unknowledgeable and 6 being very knowledgeable. For the preliminary survey, participants were asked to rank their expertise in specific aspects of knit product development as seen in figure 22. An interval scale was also employed because it is able to measure “absolute differences between scale points,” thereby allowing the primary researcher to find “absolute differences between the data” received from the respondents (Hair et al., 2008, p. 149). Additionally the data provided by the respondents enabled the evaluation instrument to rank and order the participants as novice, intermediate, or expert users.
4.2.5 Modifications to Direction Manual after Pilot 1

The direction manual was altered after Pilot 1 in order to better evaluate the participants. The direction manual used in Pilot 1 led the participants to input the correct options into the software and therefore did not test whether the participants had enough knowledge to complete the evaluation instrument. Thus, it only tested if the participants were able to accurately follow directions. The direction manual was altered to have the participants duplicate an integral knit sweater sample. The direction manual was further altered to be more general thereby encouraging the participant to make decisions for him/herself. For example, in the yarn section, the participants in Pilot 2 were given three packages of yarn without the yarn size being indicated and were then asked which yarn should be used to best duplicate the type of yarn that was used in the integral knit sweater sample. Figure 23 shows an example of how the directions assisted the participants in using the software, but did not
provide the participants with the solution as to how to duplicate the integral knit sweater sample.

4.2.6 Modifications to Post Survey after Pilot 1

The post survey was also altered after the pilot studies by adding questions that were previously in the preliminary survey. For example is the test questions that seemed to be more task oriented and more suited to following corresponding sections in the direction manual were transferred to the post survey. On the other hand, some of the test questions were removed entirely because they were too specific to the type of machinery being used in the evaluation rather than pertaining to integral knitting and the associated CAD/CAM system in general. An example of an overly specific question is, “on which side(s) of the machine is the DCSC available?” The DCSC system is only available on some Shima Seiki
integral knitting machines; therefore, this question did not help to evaluate a user of integral knitting technology as a whole. There were no other modifications made to the post survey after Pilot 1.

4.2.7 Pilot 2

After reviewing the results from the evaluation instrument, the primary researcher was able to better understand each participant self-rated expertise level. This is true, because the rating scale was modified to an ordinal interval rating scale as opposed to the previous Likert scale that the evaluation instrument implemented. It was inconclusive as to whether moving the testing questions from the preliminary survey to the post survey changed the participants’ expertise level rating that was assessed by the evaluation instrument due to the small sample size in both pilots.

As for the modifications made to the direction manual, the participants could no longer follow directions and successfully design an integral knit sweater. Through observation, the primary researcher witnessed that with the modified direction manual the participants had to make choices as to what yarn, loop length, amount of courses and wales, silhouette, and amount of fashion stitches to input into the Shima Seiki SDS-One design system in order to duplicate the integral knit sweater sample successfully. This indicated that the modified direction manual helped to guide the participants to complete a task as opposed to taking them through the process of creating an integral knit sweater without having to access any knowledge.

Out of the 17 participants tested, only one participant was unable to complete the evaluation instrument. This participant was unable to complete the evaluation instrument
because an error message came up during the course of completing the task. The error message stated: “sleeve width too wide,” indicating that when asked to count the courses and wales the participant miscounted the wales and input an amount that was too high. This error made the sleeves too wide to be knit on the integral knitting machine. The participant had to stop at part 3 (garment development section) of both the direction manual for completing the task and the post survey (please see Appendix C for the direction manual and Appendix B for the post survey). This finding implies that if a user of the CAD/CAM system for integral knitting does not know how to count courses and wales, then he/she will not be able to successfully create an integral knit product. That implication in turn validates the evaluation instrument by indicating that if a user of the CAD/CAM system is graded as a novice he/she could use training in every knowledge area in order to successfully create an integral knit product. The evaluation instrument graded the participants at the same level of the primary researcher’s anticipated skill level rating in terms of the novice, intermediate, and expert levels based upon the career positions and resumes of the participants.

4.3 Stage 3: Validation from Integral Knitting Experts

The professor of learning at North Carolina State University (NCSU) advised that, in addition to having the participant self-assess through self-rating questions, there should also be questions that test the participant in each knowledge area. This is to ensure that the participants are self-rating accurately. The professor in knitwear at Philadelphia University looked over the completed evaluation instrument and validated this process of assessing participants.
Two of the experts in training from two of the leading integral knitting machine manufacturing companies (one from Shima Seiki and one from Stoll), the expert in using the CAD/CAM system for integral knitting, and the professor in knitwear design at Philadelphia University all agreed that the knowledge bases should include: yarn; knit structure; garment development; fashioning; and machine programming. In terms of these knowledge areas, an increasing number of steps in the direction manual would imply that there is a hierarchy of knowledge areas concerning the CAD/CAM system for integral knitting. But, after speaking with two experts in training users to operate the CAD/CAM system for integral knitting, an expert in using integral knit technology, and a professor of knitwear at the college of Philadelphia University, the number of steps that need to be completed in a given knowledge area does not correlate to the importance of that knowledge area.

One of the experts in training users to operate the CAD/CAM system for integral knitting from Shima Seiki stated that machine programming was the most important section for a user to understand because one needs to understand all the functions of the software to create a garment and/or be able to knit on the electronic flat V-bed knitting machine. Contrastingly, the expert in using the CAD/CAM system for integral knitting and the professor of knitwear design at Philadelphia University indicated that garment development was the most important knowledge area, because if the user does not understand anything about garments, then the user will not be able to correctly program a garment pattern. It could also be argued that the more complicated aspects of integral knitting provided in the software offer fewer choices for the user to make, therefore reducing the number of steps in that particular section.
When the experts were asked to choose the least important knowledge area, they all indicated that the five knowledge areas were essential to successfully creating an integral knit product. The primary researcher acknowledged these statements and asked the experts to choose a knowledge area that a user could have the least knowledge about and still be able to produce an integral knit product. These experts had different views on which was the least important knowledge area. One of the experts in training users to operate the CAD/CAM system for integral knitting from Shima Seiki stated that fashioning was the least important knowledge area because there are items that can produced on the CAD/CAM system for integral knitting that do not need to have fashioning stitches. On the other hand, the expert in using the CAD/CAM system for integral knitting suggested that the least important knowledge area is yarn because through trial and error one would be able to understand what yarn will be able to knit efficiently on the electronic flat V-bed knitting machine and which yarn will not run efficiently. Contrastingly, the professor in knitwear design at Philadelphia University stated that machine programming was the least important knowledge area because users of the CAD/CAM system for integral knitting must understand all the other knowledge areas before ever using the system.

The industry expert in CAD systems for textile and apparel defined an expert as a person who has the most essential knowledge about the basic principles of the product being created by the CAD system. The expert in integral knitting and the professor in knitwear agreed that a user should be considered an expert if he or she has ten or more years of experience with about 30-40 hours a week using the integral knit technology. The one expert in training from Shima Seiki agreed that the user should have 30-40 hours per week on the
integral knit technology, but stated that he believed someone could become an expert with only using the technology for as few as 6 years. This expert maintained that it all depends on the rate at which one learns; some learn faster than others, enabling them to become experts at a faster pace. This study defines an expert as someone who has 10 or more years of experience and 30-40 hours per week using the integral knit technology.

One of the experts in training from Shima Seiki was able to explain why there is only a small population of intermediate and expert users in integral knitting who could be utilized for this research. He stated that Shima Seiki is the largest producer of integral knit products in the United States in addition to producing the knitting machinery and software. Shima Seiki designs a majority of the integral knit designs for companies that produce integral knit products. This circumstance exists because most of the products being produced are highly specialized garments and technical textiles which are extremely complex designs, and the companies producing these products do not have anyone on their staff that has the necessary skills in all five knowledge areas to produce the designs for these products. Another expert in training from Stoll qualified this statement by saying that fashion designers come to Stoll in order to have their conceptual garments made up for Fashion Week. Manufacturers who need productions samples of garments to show designs to continue business with retailers also employ Stoll’s services. Both leading experts brought to light the fact that most of the technical design for integral knit products is not happening within the companies that manufacture and sell these products due to lack of understanding in the defined five areas of knowledge. Therefore the majority of technical development is happening with a handful of people in the integral knitting manufacturing companies. Due to this dichotomy, there are not
many experts or intermediate users of the CAD/CAM system for integral knitting, because there is little market demand for this level of expertise.
Chapter 5: Conclusion and Limitations

This study aimed to create, test, and validate an evaluation instrument that could be used in future research to assess the skill level and knowledge needed to efficiently use the CAD/CAM system for integral knitting. The research was successful in that an evaluation instrument was created in Stage 1, tested in Stage 2, and industry evaluations conducted through informal interviews in Stage 3. This evaluation instrument can also be adapted to other areas of textile and apparel CAD systems, as well as CAD systems in different fields of research such as engineering. Companies and academia could use this evaluation instrument to assess the amount of knowledge someone needs before being trained on the CAD/CAM system for integral knitting.

As a result of creating, testing, and validating an evaluation instrument to assess a user of the integral knitting CAD/CAM system, other findings were uncovered, as well. During Stage 1 the major knowledge areas that are needed to understand integral knitting were discovered. Stage 2 uncovered the least understood knowledge area and the most effective structure for the evaluation instrument to correctly assess participants. The reasoning behind the scarcity of experts in integral knitting and defining an expert was revealed in Stage 3. These additional findings further exemplify the complexity of the CAD/CAM system for integral knitting.

5.1 Limitations

Limitations for this study stemmed from a lack of existing research on learning, teaching, and evaluating the CAD/CAM system for integral knitting. In addition, a large user
group of integral knitters does not exist in the United States. For these reasons, this research was primarily exploratory, and thus statistical data that could relate the findings to a larger population could not be generated. However, the primary researcher was able to reference other studies that used various types of CAD systems –most of which were for engineering– to assist with the outline of the methodology of this study.

Another limitation to this study was that only one brand of machinery was being utilized for testing the participants. Because the primary researcher only had extended access to a Shima Seiki electronic flat V-bed knitting machine and CAD system, there was no testing done on a Stoll electronic flat V-bed knitting machine and CAD system. Thus, the direction manual and some questions may have to be adapted to better assess participants when concerning integral knit technology other than what was used in this study. For example, Stoll machinery may assist the user in choosing options for the garment, thus requiring less knowledge than the Shima Seiki machinery and therefore necessitating alteration of the evaluation instrument. Additionally, the user of a Shima Seiki machine does not need to know the details of programming the machine because the CAD system loads a file onto the disk –the .999 file– that translates to the machinery the setting that will knit the product most efficiently; the same might not be applicable to Stoll technology. Because of these slight variations, it is unknown to what degree each knowledge area is needed when concerning all types of CAD/CAM systems for integral knitting. Further research is required in order to ensure the evaluation instrument is effective in the assessment of the users of the CAD/CAM systems for integral knitting on all technologies.
The third limitation was the number and type of participants who took part in this research. Unfortunately, there were a limited number of participants and the majority were considered novices; therefore, there was not much information obtained regarding intermediate and expert users. As described by an expert at Shima Seiki, it is difficult to locate the CAD/CAM system users for integral knitting; thus making it difficult to find expert users. In addition, a majority of students do not have access to learning this type of CAD/CAM system for integral knitting because availability of the technology is limited and not installed in many university locations or retail company design studios.

The amount of time allotted to this research was also a restriction. Due to the finite amount of time, only two pilot studies were conducted. Time limits also affected the period during which the evaluation instrument could be conducted. The majority of participants were only willing to participate in an activity that was able to be performed in an hour or less.
Chapter 6: Future Research

A future study based on this research should extend for a longer period of time, ranging over a number of years, to assess as many users as possible in order to yield statistical data. The research continued after this study should also extend further than the evaluation instrument that was proven valid and reliable through this study’s pilots.

A research design that would extend the population, amount of time, and depth of knowledge would be one that utilizes a college knitwear class over the course of four years. During this time period, a curriculum would be created based off of the knowledge areas and questions presented in the evaluation instrument. The students would then be assessed using the evaluation instrument created in this study at various points in each semester long course. Additionally, the information yielded from the suggested study would provide further validity to the knowledge areas defined in this study and provide more information about the knowledge needed to effectively and efficiently use the CAD/CAM system for integral knitting.

Furthers, future research should include more participants in each skill level category: novice, intermediate, and expert users. In order to achieve this task, more integral knitting experts must be identified. Future research should search internationally for expert users of the CAD/CAM system for integral knitting. This will give better-rounded and statistically robust results. In addition to a larger population and a variety of participants, future research should include various types of integral knitting machinery.
Shima Seiki, Stoll, and any other brand of electronic flat V-bed knitting machines and CAD systems, along with newer systems coming onto the market, should be utilized for future study. By using more brands of machinery, a study could indicate the complete knowledge base needed to use most types of CAD/CAM systems that are used for integral knitting and therefore provide a more rounded evaluation instrument. Testing the evaluation instrument in the product development of a company utilizing integral knitting would provide further validation. By utilizing this study as a baseline, future research will be able to see the beginning of the recognized knowledge base needed to use the CAD/CAM system for integral knitting. Thus, it will be more understood what knowledge new users will need to learn and apply to integral knitwear development when trained on the CAD/CAM system for integral knitting. Once the amount of training is evaluated, future research will help to develop better training and learning materials.

One desired outcome of this research and future related research is to increase the number of productive/efficient users of the integral knitting technology. In order to achieve this outcome, the potential users must be evaluated in order to create appropriate training materials and train new users. The topic of evaluating user level expertise for integral knitting CAD/CAM systems must be further researched in order to increase utilization of the integral knit technology and achieve the desired outcome of more productive/efficient users of the CAD/CAM systems for integral knitting.


Appendix
Appendix A- Preliminary Survey

Reva: Preliminary Survey

1. Consent Form

1. The purpose of this study is to add to the knowledge base of software capabilities and processes that support product development of integral and seamless knitting. Experts in the use of CAD for knit product design, such as yourself, are asked to complete this survey and assist in defining, describing, and quantifying the advantages and disadvantages of knit design software and how CAD programs affect the design process. The survey results will become part of the published thesis research conducted by Reva Erskine.

Your participation in this study is voluntary. You have the right to be a part of this study, to choose not to participate or to stop participating at any time. The information in the study records will be kept strictly confidential. Data will be stored securely on a password protected server accessible only by the principal investigators. SSL encryption will be used for transmitting survey results. No reference will be made in the thesis which could link you to the study. There is no monetary compensation awarded for participation in this study. However, one benefit of participating in this study is the knowledge that you will have contributed your expertise and experience to a greater body of work. There are no foreseeable risks associated with completing this survey.

If at any time you have questions about your participation, do not hesitate to contact the researchers Lisa Parrillo Chapman or Reva Erskine at the College of Textiles, Box 8301, NC State University, Raleigh NC 27695-8301 or, 919-513-4020. If you feel you have not been treated according to the descriptions in this form, or your rights as a participant in research have been violated during the course of this project, you may contact Dr. Arnold Bell, Chair of the NC State University IRB for The Use of Human Subjects and Research Committee, Box 7514, NC State University (919/515-3086), or Mr. Mathew Ronning, Associate Vice Chancellor, Research Administration, Box 7514, NC State University (919/515-2148).

By checking the “I accept” box I acknowledge that I understand the above information. You may print a copy of this agreement for your records.
**Reva: Preliminary Survey**

- [ ] I accept
- [ ] I do not accept
Reva: Preliminary Survey

2. Contact Information

1. Please provide the following contact information. This information will be kept confidential.
   - Name:
   - Company:
   - Address:
   - Address 2:
   - City/Town:
   - State:
   - ZIP/Postal Code:
   - Country:
   - Email Address:
   - Phone Number:

2. What is your job title?

3. What are your main responsibilities in your current position?

4. How long have you been employed in your current position?
**Reva: Preliminary Survey**

**3. Experience**

1. **How often do you use computer aided design (CAD)?**
   - [ ] Daily
   - [ ] Once or twice a week
   - [ ] Once a month
   - [ ] Four times a year
   - [ ] Once a year
   - [ ] Never

2. **What type of CAD/CAM systems have you used? Check all that apply.**
   - [ ] Knitwear CAD (such as Shima Seiki and Stoll)
   - [ ] Pattern Making CAD (such as Lectra and Gerber)
   - [ ] Weaving CAD (such as EAT, Kaledo)
   - [ ] Textile Design CAD (such as Pointcarré and Photoshop)

3. **How long have you been working with knit product development?**
   - [ ] 0-3 years
   - [ ] 4-6 years
   - [ ] 7+ years

4. **Please answer how long you have used the following categories in years (please round up).**
   - CAD
   - Knitting CAD
   - Integral Knitting CAD

5. **Please state the number of hours per week that you typically use CAD systems.**
   - CAD
   - Knitting CAD
   - Integral Knitting CAD

6. **Have you ever had training on the following items?**
   - CAD/CAM in general
   - Knitting CAD/CAM
   - Specifically Integral Knitting CAD/CAM
<table>
<thead>
<tr>
<th>Question</th>
<th>Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>7. Do you feel that adequate literature and training material exists for</td>
<td>No, I learned by trial and error</td>
</tr>
<tr>
<td>software for knit product development? Please check all that apply.</td>
<td>No, I would still like training</td>
</tr>
<tr>
<td></td>
<td>No, I can't find published material on knit software</td>
</tr>
<tr>
<td></td>
<td>Yes, my educational experience prepared me</td>
</tr>
<tr>
<td></td>
<td>Yes, my past or current organization trained me well</td>
</tr>
<tr>
<td></td>
<td>Yes, there are well documented strategies on the web for CAD for knit design</td>
</tr>
<tr>
<td></td>
<td>Yes, there are books and papers that explain how to design with knit product development software</td>
</tr>
<tr>
<td></td>
<td>Other (please specify)</td>
</tr>
<tr>
<td>8. Do you feel that adequate literature and training material exists for</td>
<td>I have never worked on integral knit software</td>
</tr>
<tr>
<td>software for integral knit product development? Please check all that</td>
<td>No, I learned by trial and error</td>
</tr>
<tr>
<td>apply. Integral Knitting is defined by Spencer (2001) as a knit product</td>
<td>No, I would still like training</td>
</tr>
<tr>
<td>whose various parts have been knit-assembled by the knitting machine.</td>
<td>No, I can't find published material on knit software</td>
</tr>
<tr>
<td>It requires minimal make-up attention on leaving the knitting machine.</td>
<td>Yes, my educational experience prepared me</td>
</tr>
<tr>
<td></td>
<td>Yes, my past or current company trained me well</td>
</tr>
<tr>
<td></td>
<td>Yes, there are well documented strategies on the web for CAD for knit design</td>
</tr>
<tr>
<td></td>
<td>Yes, there are books and papers that explain how to design with knit product development software</td>
</tr>
<tr>
<td></td>
<td>Other (please specify)</td>
</tr>
</tbody>
</table>
Reva: Preliminary Survey

9. Please rate your experience with CAD/CAM training as it pertains to the following questions.

<table>
<thead>
<tr>
<th></th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neutral</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. I feel training has greatly increased my understanding</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>b. I feel without training I would not understand the software</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>c. I felt my instructor was knowledgeable about the CAM/CAM system</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>d. I feel I need more training on the CAD/CAM system</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

10. When learning a specific CAD/CAM system were you given a manual or other learning tool? If yes please describe what kind of learning tool and what kind of CAD/CAM system

   ○ No
   ○ Yes

11. Have you ever used an electronic flat V-bed knitting machine or its CAD/CAM system?
Check all that apply

   ○ No
   ○ Yes, the CAD (software)
   ○ Yes, the CAM (machine programming)
   ○ Yes, Running the machine
Reva: Preliminary Survey

12. Please rate your level of expertise on the following areas of knit product development as it pertains to knitting on a scale from 1-6, with 1 being Very Unknowledgeable and 6 being Very Knowledgeable.

<table>
<thead>
<tr>
<th>Area</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Yarn Properties</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. Yarn numbering systems</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. Loop Length</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d. Knit Structure</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>e. Garment Silhouette</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>f. Sizing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>g. Fashioning</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>h. Package Development</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>i. Machine Parameters</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

13. Please state your years of experience in the following areas of knit product development.

<table>
<thead>
<tr>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Yarn Properties</td>
</tr>
<tr>
<td>b. Yarn numbering systems</td>
</tr>
<tr>
<td>c. Loop Length</td>
</tr>
<tr>
<td>d. Knit Structure</td>
</tr>
<tr>
<td>e. Garment Silhouette</td>
</tr>
<tr>
<td>f. Sizing</td>
</tr>
<tr>
<td>g. Fashioning</td>
</tr>
<tr>
<td>h. Package Development</td>
</tr>
<tr>
<td>i. Machine Parameters</td>
</tr>
</tbody>
</table>
Reva: Preliminary Survey

4. Organization Information

1. What type of equipment are you using or have used in the past? Please check all that apply.
   - Circular seamless body-size
   - Circular cylinder and dial
   - Straight bed
   - Hand V-bed
   - Electronic v-bed
   - Other (please specify):

2. If you checked an item in the previous question, what type of knit products have you developed? Check all that apply
   - Fabric Samples
   - Apparel Items
   - Intimate Apparel
   - Hosiery
   - Exclusively Sportswear
   - Gloves
   - Industrial Products
   - Medical Textiles
   - Automotive Textiles
   - I did not check an item in the previous question
   - Other (please specify):
5. Knitted Design: Process

1. Are you responsible for designing, the design of the silhouette, knit structure, and any graphics? Check all that apply.
   - Silhouette
   - Knit Structure
   - Graphics
   - Machine Operations
   - Sizing
   - Other (please specify)

2. Are you responsible for supervising, the design of the silhouette, knit structure, and any graphics? Check all that apply.
   - Silhouette
   - Knit Structure
   - Graphics
   - Machine Operations
   - Sizing
   - Other (please specify)
Reva: Preliminary Survey

6. Part 1 Yarn

1. The following set of questions ask you to rate your knowledge of yarn and fiber. Please specify your level of agreement or disagreement with the following statements:

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neutral</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. I know how to choose the appropriate yarn size for a specific machine gauge.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>b. I understand the importance of choosing the appropriate yarn size for a specific machine gauge.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>c. I understand that yarn behaves differently when knit based on fiber type.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>d. I understand that different finishes (washing, drying, etc.) have an effect on different fibers.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>e. I am confident in choosing the correct yarn for a specific machine.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

2. How often are you responsible for the type of yarn to use when knitting?

- Daily
- Once or twice a week
- Once a month
- Four times a year
- Once a year
- Never

3. Please state the average number of hours per week that you typically spend working with yarn. Please round up to the full hour.

[Blank space for input]

4. Please state how long you have been working with yarn in years. Please round up to the full year.

[Blank space for input]
### 7. Part 2 Knit Structure

1. The following set of questions ask you to rate your knowledge of loop length. Please specify your level of agreement or disagreement with the following statements:

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neutral</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. I understand why it is necessary to run a loop routine.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. I understand why it is important to evaluate a loop routine.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. I feel confident in evaluating a loop routine.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d. I understand what Digital Stitch Control System (DSCS on the Shima Seiki machine) is.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>e. I understand how to count courses.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>f. I understand how to count wales.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>g. I understand what fabric density is.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>h. I am confident in calculating fabric density.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>i. I understand the importance of calculating the fabric density.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. How often are you responsible for determining the appropriate loop length for a knitted item?

- Daily
- Once or twice a week
- Once a month
- Four times a year
- Once a year
- Never

3. Please state the average number of hours per week that you typically spend working with loop length. Please round up to the full hour.
Reva: Preliminary Survey

4. Please state how long you have been working with loop length in years. Please round up to the full year.

5. How often are you responsible for specifying the knit structure of a knitted item?
   - Daily
   - Once or twice a week
   - Once a month
   - Four times a year
   - Once a year
   - Never

6. Please state the average number of hours per week that you typically spend working with knit structures. Please round up to the full hour.

7. Please state how long you have been working with knit structure in years. Please round up to the full year.
Reva: Preliminary Survey

8. Part 3 Garment Development

1. The following set of questions ask you to rate your knowledge of garment silhouettes. Please specify your level of agreement or disagreement with the following statements:

<table>
<thead>
<tr>
<th></th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neutral</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. I understand the difference between different sleeve types (ex: raglan, set in, epaulette, etc.)</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>b. I feel confident in choosing the garment silhouette.</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>c. I understand the difference in neck lines (v-neck, turtle neck, crew, etc.)</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>d. I understand that the garment silhouette is not limited only to sleeve styles and neck lines.</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>e. I understand how the fabric density relates to the size of the garment.</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>f. I understand garment sizing.</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>g. I am confident I am able to pick the right size for given measurements.</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
</tbody>
</table>

2. How often are you responsible for specifying the garment silhouette for a specific garment?

- Daily
- Once or twice a week
- Once a month
- Four times a year
- Once a year
- Never

3. Please state the average number of hours per week that you typically spend working with garment silhouette. Please round up to the full hour.

4. Please state how long you have spent working with garment silhouette in years. Please round up to the full year.
### Reva: Preliminary Survey

5. How often are you responsible for specifying the sizing of a specific garment?
- [ ] Daily
- [ ] Once or twice a week
- [ ] Once a month
- [ ] Four times a year
- [ ] Once a year
- [ ] Never

6. Please state the average number of hours per week that you typically spend working with garment sizing. Please round up to the full hour.

   

7. Please state how long you have spent working with garment sizing in years. Please round up to the full year.

   

Reva: Preliminary Survey

9. Part 4 Fashioning

1. The following set of questions ask you to rate your knowledge of pattern development and programming.

Please specify your level of agreement or disagreement with the following statements:

<table>
<thead>
<tr>
<th>a. I understand what fashioning stitches are.</th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neutral</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>b. I understand what knitting efficiency is.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. I understand how a fashioning sequence affects the knitting efficiency.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d. I understand how the silhouette affects the fashioning sequence.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>e. I understand how to calculate a fashioning sequence.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>f. I understand the difference between inside and outside fashioning.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>g. I understand how to use widening or narrowing stitches to shape a garment.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. How often are you responsible for specifying the garment fashioning?

- Daily
- Once or twice a week
- Once a month
- Four times a year
- Once a year
- Never

3. Please state the average number of hours per week that you typically spend working with garment fashioning. Please round up to the full hour.

4. Please state how long you have spent working with garment fashioning in years. Please round up to the full year.
Reva: Preliminary Survey

10. Part 5 Machine Programming

1. Please rate your level of expertise on the following areas of knit product development and knitting machine programming/set-up as it pertains to knitting on a scale from 1-5, with 1 being Very Unknowledgeable and 6 being Very Knowledgeable.

<table>
<thead>
<tr>
<th>Area</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Yarns in and out</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. Location of carriers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. Number of carriers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d. Loop length</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>e. Yarn tension</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>f. Fabric take-down tension</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>g. Speed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. How often are you responsible for the knitting machine programming?

- Daily
- Once or twice a week
- Once a month
- Four times a year
- Once a year
- Never

3. Please state the average number of hours per week that you typically spend working with knit machine programming. Please round up to the full hour.

4. Please state how long you have spent working with knitting machine programming in years. Please round up to the full year.
### Reva: Post Survey

#### 1. Post Survey

Using your prior knowledge of integral knitting and knit product development, you have been asked to design an integrally knitted sweater using Shima Seiki SDS One CAD/CAM system. This task is divided into five sections: yarn properties, knit structure, garment development, fashioning, and knitting machine programming. You will be given the following tools:

- Knit samples
- Integrally knitted garment sample
- Pick glass
- Tape measure
- SDS One workstation
- Set of directions

Please examine the integrally knitted sweater with the tools given to you and attempt to duplicate the garment within the SDS One software. After each section the researcher will ask you to provide feedback on the tasks completed.
Reva: Post Survey

2. Part 1 Yarn

Using a tape measure and a pick glass, please examine the knit sample given to you by the primary researcher. Based on this examination, and your prior experience and knowledge of yarn properties, choose the yarn that will duplicate the integrally knit sweater sample.

1. Please rate your level of agreement for the following statements:

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neutral</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. I felt as though I had sufficient prior knowledge of yarn properties to complete the first task.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>b. I felt confident that the information I input in part one was the best choices for this part of the development process for the integrally knit sweater.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>c. I understood part one from my prior experiences of yarn properties</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

2. Which yarn size did you choose in order to duplicate the integral knit sweater sample?

- ○ 8/2 Ne
- ○ 12/1 Ne
- ○ 20/2 Ne

3. The machine gauge is measured by the number of needles per unit length (for example: number of needles per inch).

- ○ True
- ○ False
- ○ I'm not sure

4. List the indirect yarn numbering systems.

5. List the direct yarn numbering systems.
Reva: Post Survey

6. Of the following yarn sizes please pick the appropriate size(s) that would run most efficiently through a 7 gauge electronic flat V-bed knitting machine when threaded with only one end of yarn.

☐ 30/1 No
☐ 20/2 No
☐ 60/1 No
☐ 8/2 No
☐ I'm not sure

7. Which type of yarn will torque less when knit?

☐ 2 ply yarn
☐ Single ply yarn
☐ I'm not sure

8. When using the electronic flat V-bed knitting machine it is important to choose a yarn with some elongation.

☐ True
☐ False
☐ I'm not sure

Please use Figure 1 and Figure 2 for the following questions. Each picture is a one inch square of a piece of jersey material (the front and back).

Figure 1

Figure 2
Reva: Post Survey

9. Which figure above is the technical front of jersey knit fabric?

- [ ] Figure 1
- [ ] Figure 2
- [ ] I'm not sure
Reva: Post Survey

3. Part 2 Knit Structure

Using a tape measure and a pick glass, please examine the knit sample given to you by the primary researcher. Based on this examination, and your prior experience and knowledge of knit structure properties, choose the loop length that will duplicate the integrally knit sweater sample.

1. Please rate your level of agreement on a scale of strongly agree to strongly disagree for the statements below:

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neutral</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. I felt as though I had sufficient prior knowledge of knit formation properties to assess the loop routine.</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>b. I felt confident that the information I input for the loop routine was correct.</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>c. My prior knowledge of knit formation helped me to understand part two.</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

2. Which loop routine did you choose to evaluate in order to best replicate the loop length of the integral knit sweater sample?

- Sample 1
- Sample 2

3. What loop size did you choose from the loop routine that duplicates the knit structure on the integral knit sweater sample?

- 11
- 10.5
- 10
- 9.5
- 9

4. Please indicate how many courses and wales you have counted in a 1x1 inch square on the sample loop routine.

<table>
<thead>
<tr>
<th>Courses</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Wales</td>
<td></td>
</tr>
</tbody>
</table>

5. Please explain the purpose of a loop routine.
Reva: Post Survey

6. If you were to change the type of yarn, but still used the same pattern on the machine would you need to run a loop routine again?

☐ Yes
☐ No
☐ I'm not sure
4. Part 3 Garment Development

Using a tape measure and a pick glass, please examine the integrally knit sweater given to you by the primary researcher. Based on this examination, and using your prior experiences and knowledge of knit garment development, please choose the silhouette and sizing that best duplicates the integrally knit sweater sample.

1. Please rate your agreement from strongly agree to strongly disagree for the statements below on garment silhouette:

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neutral</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. I understood how to choose the general silhouette for the integral knit pattern (step 5).</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>b. I felt as though I had sufficient prior knowledge of garment silhouette properties to complete the tasks within part three.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>c. I felt confident that the information I input in part three was the best choices for garment silhouette to best duplicate the integrally knit sweater sample.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

2. Which sleeve type did you choose within the software program that most closely matched the integrally knit sweater sample?

- ○ Set-in A
- ○ Set-in B
- ○ Raglan
- ○ Epaulette
- ○ Parachute

3. Which neckline type within the software program did you choose in order to duplicate the integrally knit sweater sample?

- ○ V-neck
- ○ Turtle neck
- ○ Crew (round) neck
Reva: Post Survey

Please use this picture to help answer the following question.
Raglan versus Set-in sleeve (Brackenbury, 1992)

4. Please examine the pictures shown above that depict a raglan sleeve and a set-in sleeve. Based on your knowledge of integral knitting, please pick which sleeve type would take the most time to knit?

☐ Raglan sleeve
☐ Set-in sleeve
☐ I'm not sure

5. Please explain why you chose your specific answer for question 4.
Reva: Post Survey

Below are different garment silhouettes, please use the corresponding letter to answer the following questions.

6. Which of these silhouettes is a "parachute" silhouette?
   - [ ] A
   - [ ] B
   - [ ] C
   - [ ] D
   - [ ] I'm not sure

7. Which of these silhouettes has a "V" neck?
   - [ ] A
   - [ ] B
   - [ ] C
   - [ ] D
   - [ ] I'm not sure
**Reva: Post Survey**

8. Please rate your agreement from strongly agree to strongly disagree for the statements below on garment sizing:

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neutral</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. I understood how to count and input the courses and wales into the program in order to determine sizing (steps 6-8).</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>b. I understood how to choose the size that best duplicates the sample integrally knit sweater (steps 9-10).</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>c. I felt as though I had sufficient prior knowledge of sizing properties to complete the tasks within part three.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>d. I felt confident that the information I input in part three was the best choices for garment sizing to best duplicate the integrally knit sweater sample.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

9. Examine the sweater again and look over the measurements provided within the SDS. One software program in step 9 (Size Input) and choose the correct size needed to create a duplicate of the integrally knit sweater sample.

- S
- M
- L
- XL

10. To get the correct sizing for an integrally knit garment when inputting the courses and wales it is best to:

- Count the courses and wales on the sample piece before the finishing processes are applied to the sample piece.
- Count the courses and wales on the sample piece after the finishing processes are applied to the sample piece.
- I'm not sure.

11. When the loop length is increased what happens to the weight of the fabric?

- It becomes heavier.
- It becomes lighter.
- I'm not sure.
Reva: Post Survey

5. Part 4 Fashioning

Using a tape measure and a pick gauge, please examine the integrally knit sweater given to you by the primary researcher. Based on this examination, and using your prior experiences and knowledge of knit fashioning, please choose the correct fashioning sequences and shaping methods that will duplicate that of the integrally knit sweater sample.

1. Please rate your level of agreement from strongly agree to strongly disagree for the following statements on knit fashioning:

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neutral</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. I understood how to change the narrowing stitches (steps 15-16)</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>b. I felt as though I had sufficient prior knowledge of fashioning techniques to complete the tasks within part four.</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>c. I felt confident that the information I input in part three was the best choices for this part of the development process for the integrally knit sweater.</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>d. I understand fashioning properties from my prior experiences.</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>e. I understood why I needed to input the information required within the CAD program.</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
</tbody>
</table>

2. To duplicate the sample integral knit sweater did you choose to use inside or outside widening for the fashioning stitches?

- Inside
- Outside
- I'm not sure

3. Please indicate the total number of fashioning stitches per course that you chose in order to duplicate the integrally knit sweater sample.

4. Typically what is the highest number of recommended needles to be fashioned in one sequence in one course?


### Reva: Post Survey

5. Please rate your level of agreement from strongly agree to strongly disagree for the following statements on knit shaping:

<table>
<thead>
<tr>
<th></th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Undecided</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. I understood why I chose the type of curve for the front, back, and sleeve of the integral knit pattern (steps 11-14).</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. I felt as though I had sufficient prior knowledge of shaping techniques to complete the tasks within part four.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. I felt confident that the information I input in part three was the best choices for this part of the development process for the integrally knit sweater.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d. I understand shaping properties from my prior experiences.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>e. I understood why I needed to input the information required within the CAD program.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6. If you have an "original" curve on the front of the sweater's armhole you are able to have a "curve 2" on the sleeve of the sweater.

- True
- False
- I'm not sure

7. Please choose the structure that will best duplicate the structure in the integral knit sweater sample is knit in.

- 1x1 Jersey
- 1x1 Rib
- Full Cardigan
- 2x2 Cable Jersey
- I'm not sure
Reva: Post Survey

8. With in the Initialize and Outline Adjust window, the alignment tab enables the user to do what to the integral knit pattern?
   - [ ] Change the narrowing fashionings
   - [ ] Align the sleeve pattern pieces and the bodice pattern pieces
   - [ ] Align the fashionings on both the right and left side
   - [ ] None of the above
   - [ ] I'm not sure

9. What is the difference between a "j-curve" and a "s-curve" under the arm at the sleeve widening?
   - [ ] The J-curve allows more elbow ease in the underarm widening
   - [ ] The S-curve allows more elbow ease in the underarm widening
   - [ ] There is no ease added to either
   - [ ] I'm not sure
Reva: Post Survey

6. Part 5 Machine Programming

Please examine the integrally knit sweater given to you by the primary researcher. Based on this examination, and using your prior experiences and knowledge of knit machine programming, please choose the correct settings and parameters that will duplicates the integrally knit sweater sample and knit the most efficiently.

1. **Please rate your level of agreement from strongly agree to strongly disagree for the following statements:**

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. I understood how to develop a package for the integral knit pattern (steps 23-26)</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>b. I understood how to determine the carrier location on the machine to knit the integral knit pattern (steps 30-31).</td>
<td>○</td>
<td></td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>c. I understood how to simulate the integral knit pattern in order to check for errors (steps 37-38).</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>d. I felt as though I had sufficient prior knowledge of machine programming properties to complete the tasks within part five.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>e. I felt confident that the information I input in part one was the best choices for the part of the development process for the integrally knit sweater.</td>
<td>○</td>
<td>○</td>
<td>○</td>
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</tr>
<tr>
<td>f. I understood this section from my prior experience of machine programming (set-up).</td>
<td>○</td>
<td></td>
<td>○</td>
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</tr>
<tr>
<td>g. I understood why I needed to input the information required within the CAD program.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

2. **Was there an error message at the end after the knit was simulated?**

- ○ Yes
- ○ No
Reva: Post Survey

3. Please choose the correct function for each carrier when knitting a wholegarment integrally knit sweater on the Shima Seiki N SWG-V Wholegarment knitting machine

| Carrier 1 right | | | | | | | |
| Carrier 1 left | | | | | | | |
| Carrier 2 right | | | | | | | |
| Carrier 2 left | | | | | | | |
| Carrier 3 right | | | | | | | |
| Carrier 3 left | | | | | | | |
| Carrier 4 right | | | | | | | |
| Carrier 4 left | | | | | | | |
| Carrier 5 right | | | | | | | |
| Carrier 5 left | | | | | | | |
| Carrier 6 right | | | | | | | |
| Carrier 6 left | | | | | | | |
| Carrier 7 right | | | | | | | |
| Carrier 7 left | | | | | | | |
| Carrier 8 right | | | | | | | |
| Carrier 8 left | | | | | | | |

Yarn/Carrier Function

4. A whole garment is knitted in half gauge.
   - True
   - False
   - I'm not sure.

5. Please explain why you chose the specific answer for question 4.

6. What is a “jump”?
   - A command to tell the machine to skip, or "jump" certain courses.
   - A knitting sequence that is repeated multiple times.
   - A command to tell the machine to look for information else where.
   - I'm not sure.
<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>7. What are the three places within the SDS One CAD system and knitting machine that you are able to change the take-down?</td>
<td></td>
</tr>
<tr>
<td>8. Changing the take-down number adjusts which two aspects of the roller on the knitting machine?</td>
<td></td>
</tr>
</tbody>
</table>
Using your prior knowledge of integral and/or knit product development, you have been asked to design an integrally knitted sweater using Shima Seiki SDS-One CAD/CAM system. This task is divided into five sections: yarn/fiber properties, loop length/knit structure, garment silhouette, fashioning/shaping, and knitting machine programming/set-up. You will be given the following tools:

- Knit samples
- Integrally knitted garment sample
- Pick glass
- Tape measure
- SDS-One workstation
- Learning module-directions

Please examine the integrally knit sweater with the tools given to you and attempt to duplicate the garment within the SDS-One software. After each section the researcher will ask you to provide feedback on the tasks completed.
Part 1:
Choosing the Yarn

1. The whole garment machine, N-SWG, that you will be using is a 7 gauge machine. (You can double check this on the software when you select the machine type.) Being a 7 gauge machine means that there is 7 needles per inch. The machine takes courser yarns in order to knit outer-wear.

2. Using a tape measure and a pick glass, please examine the knit sample given to you by the primary researcher. Based on this examination, and your prior experience and knowledge of yarn properties, choose the yarn size that will correctly duplicate that in which you see in the sample integrally knit sweater.

[STOP]
Part 2:
Loop Routine

1. The loop routine has already been run for you in order to cut down on the time of the learning module and to optimize the success of your garment being knit. Using a tape measure and a pick glass, please examine the knit sample given to you by the primary researcher. Based on this examination, and your prior experience and knowledge of loop length and knit structure properties, choose which sample loop routine to evaluate and then the correct loop length that will accurately duplicate that in which you see in the sample integrally knit sweater.

2. Please count and record the number of courses and wales within a 1 x 1 inch square.
Part 3: Picking the Garment Silhouette and Sizing

1. Using a tape measure and a pick glass, please examine the integrally knit sweater given to you by the primary researcher. Based on this examination, and using your prior experiences and knowledge of knit garment silhouettes, please choose the silhouette and sizing that best duplicates that of the sample integrally knit sweater. Please click the "KnitPaint" Button to begin creating a "Wholegarment":

Welcome to KnitPaint blank screen:
2. Please click “New” in the upper right hand corner to start a new pattern.

3. The new file window will pop up:
   - Name your file (where is says “Name”)
   - Make sure that the "WG" tab is selected such as below in order to create a “Wholegarment”
   - In the “Shape” section should have “Sweater” and then choose the correct silhouette type from the drop down menu
   - Input Mode should have “Size” selected in order to be able to change how big or small the garment will be
   - Gauge Input should be “Normal input”; the other option is 3 piece input which would be used when running a test piece; it allows the user to choose multiple loop lengths.
4. After everything is selected correctly click "Exec." This will allow you to go to the next step of designing.

The picture directory of the garment types will pop up:
5. Please click the picture with the garment silhouette that best duplicates that of the sample integral knit sweater that was given to you by the primary researcher. See Figure 14 (below) for an example.

6. Please view the loop routine sample you chose, and have the number of courses and wales you had counted in a 1 x 1 inch square available for the next steps.

7. The gauge input window will pop up displaying the pattern pieces and the course and wale size. Input the number of wales and courses you have counted and then change the “4” in front of inch to “1”. Click "OK":

![Gauge Input Window](image)
8. This window will pop up to verify where you have saved your file, click "OK":

![Image of OK button]

Sweater directions.GPW (Gauge)
Saved into D:\Reva Shima Soli\Sweater directions.

9. The size input will then pop up. Choose which ever size you would like (S,M,L, or LX) and then click "Decide" to continue designing.

10. This window will pop up to inform you where everything has been saved, click "OK":

![Image of OK button]

Sweater directions.SCH (Measurement Table), Sweater directions.PPT (Pattern), Sweater directions.RUL (Rule Formula)
Saved into D:\Reva Shima Soli\Sweater directions.

[STOP]
Part 4: Fashioning and Shaping

11. Using a tape measure and a pick glass, please examine the integrally knit sweater given to you by the primary researcher. Based on this examination, and using your prior experiences and knowledge of knit fashioning and shaping, please choose the correct fashioning sequences and shaping methods that best duplicates that of the sample integrally knit sweater. This window will pop up to ask if you would like to create an "original curve" for the front bodice, click "No":

![Image of a pattern with a window asking to confirm whether to change the curved line to original](image-url)
12. The pattern narrowing edit window will pop up to allow you to change the types of curve, please change all curves to “WG Curve 2” on the A.H.(arm hole), Body, and Collar tabs (as shown below) and then click “OK”.
13. The pattern narrowing edit window will pop up to allow you to change the types of curves for the back bodice, please select "WG Curve 2" for the A.H., Body, and Collar tabs and then click "OK"
14. The pattern narrowing edit will pop up to allow you to change the types of curve for the sleeve, please select “WG Curve 2” and then click “OK”.

15. The initialize and outline adjust will then pop up, please click “Execute”.
16. The “Initialize Pattern” window will then pop up. Please click “OK”.

17. The “Slide Process” window will pop up; please click the “Arm Hole” tab. After examining the integral knit sweater sample please choose the number of narrowing and widening stitches that will duplicate the sample and adjust the “Num. of Courses accordingly.”
18. Now click the “Sleeve Widening” tab. Once again after examining the integral knit sweater sample please select the best way to duplicate the sweater in reference to the “Inside Widening” and the “Num. of Courses”. Then click “Execute”.

![Sleeve Widening screenshot]

19. Please click on the icon called WG Knit Set:
20. The WG Knit Set window will then pop up in order to give you more options in altering your pattern. For this exercise you will be only altering a couple things within the entire WG Knit Set, please follow below to understand what each tab offers.

- In the “Connection” section please check “knotting”.  

![Image of WG Knit Set window highlighting the Connection tab and the Knotting option]
- In the “Open/Close pos.” tab please select the “Set the position of Main roller open/close” box. One you do this your curser will turn into a small hand where you can place the blue bars such as above in order to open and then close the rollers during knitting to ensure there is the right amount of pull on the garment when it is being knit. Place the blue bars where there appears to be a lot of fashioning happening; such as where the sleeves are being connected and the neckline. Have yours look similar to the picture below.

- The “Etc.” tab gives you the ability to make more bind off decisions, leave what is selected. Please click “OK” to save the couple of changes you have made in the WG Knit Set.
21. You will then see this screen when you are finished developing the pattern:
[STOP]
Part 5: Machine Programming (Machine Set-up)

22. Please examine the integrally knit sweater given to you by the primary researcher. Based on this examination, and using your prior experiences and knowledge of knit machine programming (set-up), please choose the correct settings and parameters that will best duplicates that of the sample integrally knit sweater and knit the most efficiently. Please click the blinking “S Paint” button in the upper right hand corner:

23. This window will pop up asking if you would like to over write your previous file, click “Yes”.

![Warning Window]

D:\Reva Shima Seiki\Sweater directions already exists. Overwrite OK?

[Yes] [No]
24. You will then see your pattern in the compressed format:

25. Please the Package ("PAC") button in the upper right hand corner:
26. A side tab will pop up, click “Package Development”:

27. The package development window will pop up for package development verification, click “Exce.” The settings do not need to be changed.
28. Your pattern will then look like the Figure 40 below as the developed version:
29. Click the knitting needle icon in the upper right hand corner..
30. The automated software settings will pop up. This section allows you to pick the machine that you are using to knit the garment. Please make sure the selections look like the picture below in order to get the right parameters of the knitting machine, click “Execute Auto”:
31. The area window will then pop up. Click in the center part of your pattern so it selected and surround by a moving dotted line (marching ants). This will ensure which pattern you are picking to knit on the machine (there can sometimes be more than one pattern on a page); Then click "OK":
32. The “Auto Process Parameters” window will pop up, make sure in the “Fixed Data” tab that the “waste yarn” is set to 6, as shown below.
33. The other tab that needs to be check is “Carrier”. Please change the “I” next to carrier 8 to an “N” because our machine is outfitted with “normal” carriers (N) and no “intarsia” carriers (I). Make sure the window looks like the picture below:

![Auto Process Parameters](image)

34. Now at the top left under “Output Device” select A:\, in order for it to be saved to the disk:
35. Now click the big, red "Execute" button to save your pattern to the disk:
36. Click “OK” to verify this is the data you would like to output:

![Output Data Window]

- File name: A/.../Sweater directions 000
- Total knit course: 1720
- Pattern data value: 672 wale x 2027 courses
- Control data value: 1268 blocks

- Pattern data: 1
- Control main data: 1
- Control sub data: 1-31
- Jump econo data: 1
- Yarn carrier data: 1
- Pattern dev data: 4
- Yarn carrier position data: 1

37. This window will pop up to double check the machine you are using, make sure the window looks like the picture below and click “OK”

![Adjustment Data Output Window]

- Machine type: NSWG-V 7G
- Knitting type: Half gauge
- Style: Sweater

![OK Button]
38. This window will pop up explaining the .999 file was saved, press "OK"
39. This window will then pop up to allow you to check if your pattern will accurately knit on the machine. Click “Simulation Start”

40. If there are no errors in the pattern in the box it will say “No Error Found” and the pattern is then ready to be put into the machine to be knit.
## Appendix D - Rubric

### Yarn

<table>
<thead>
<tr>
<th></th>
<th>Expert</th>
<th>Intermediate</th>
<th>Novice</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Years of experience</strong></td>
<td>10 or more</td>
<td>5-9</td>
<td>0-4</td>
</tr>
<tr>
<td><strong>Frequency used during a year</strong></td>
<td>Daily, Once or twice a week</td>
<td>Once a month</td>
<td>Four times a year</td>
</tr>
<tr>
<td><strong>Hours a week</strong></td>
<td>30 +</td>
<td>15-29</td>
<td>0-14</td>
</tr>
<tr>
<td><strong>Numbers of test questions answered correctly</strong></td>
<td>6-7</td>
<td>4-5</td>
<td>0-3</td>
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<tr>
<td><strong>Steps that were able to be completed in the learning manual</strong></td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td><strong>Assistance needed (number of times needed help to complete a task/questions asked)</strong></td>
<td>0-1 times</td>
<td>2-3 times</td>
<td>4+ times</td>
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<tr>
<td>----------------------------------------------------</td>
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<td>4+ times</td>
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<td>Years of experience</td>
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## Machine Programming

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<td>Frequency used during a year</td>
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<td>times needed help to complete</td>
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<tr>
<td>a task/questions asked)</td>
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### Integral Knitting Summation

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<td>6-10 times</td>
<td>11+ times</td>
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</table>
Appendix E- Cover Letter

Reva Erskine  
North Carolina State University  
Textile and Apparel Technology Management

Dear participants,

The College of Textiles at NC State University is conducting research to study the capabilities and limitations of computer aided design (CAD) and computer aided machinery (CAM) system in association with integral and seamless knitting. Your participation in this study is voluntary and any data that you provide will be held confidential.

The goal of this research is to create a snapshot of the knowledge base needed by users to effectively use the CAD/CAM system for integral and seamless knitting. You are being asked to participate in this study due to the fact that you have been involved with knitwear production. We would appreciate your input in order to refine the methodology for any future researchers. This research includes a pre-survey, learning module, and post-survey that will take the participant at most 2 hours to complete and will be administered the primary researchers at the College of Textiles.

Your cooperation is greatly appreciated. If you have any questions concerning this study, please contact me at rserskin@ncsu.edu

Sincerely,

Reva Erskine

Graduate Student  
North Carolina State University  
MS Textiles program, Textile and Apparel Technology and Management

Lisa Parrillo-Chapman, Ph. D.  
Professor—NCSU  
lparril@ncsu.edu
Appendix F- Questions Provided to Industry Experts for Validation

1. Do you agree that the knowledge bases needed to use the CAD/CAM system for integral knitting are yarn, knit structure, garment development, fashioning, and machine programming?

2. Which area do you find the most important when creating a knitted garment (yarn, knit structure, garment development, fashioning, or machine programming)?

3. Is a user with minimal experience and knowledge about the CAD/CAM system for integral knitting able to produce a knit product due to the software’s assistance?

4. How many years and hours per week on the CAD/CAM system for integral knitting would you consider an expert to have?

5. The participants in this study are given a preliminary survey to self-assess their knowledge, then are instructed to complete the task of creating and integral knit sweater, and then lastly are given another survey to self-assess again and be asked testing questions to verify the participant’s self-assessment is correct. Do you agree with this method?