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Teaching Sustainability in Fashion Design Courses Through a Zero-Waste Design Project

Hae Jin Gam[1] and Jennifer Banning[2]

Abstract

With the increased importance of learning about sustainability in fashion design curriculum, this article reports the teaching zero-waste design in existing fashion design courses that teach skills needed to create and construct garments. This study documents the development and delivery of a zero-waste design project in two different levels of fashion design courses. Data were collected before and after the zero-waste design project implementation. By learning about zero-waste design, students' interest in sustainable living and fashion and consciousness about generating fabric waste was increased. Written comments about student experiences also supported these findings and indicated that the zero-waste design project positively influenced their awareness of sustainability practices.

Keywords

active learning, production, apparel design, sustainability, teaching

In fashion design curriculum, product development and patternmaking are fundamental courses, where students continuously learn to develop their skills in garment design and construction. In the fashion design and merchandising program at a Midwestern University in the United States, the product development course is an introductory offering, where students learn basic sewing skills and how to apply them in simple garments. Patternmaking courses are more advanced and allow students to apply construction skills while they explore their creative potential in more challenging garments. Along with increasing awareness of environmental problems and social issues, introducing sustainability practices in various fashion merchandising and design courses has been explored in a number of studies (Fletcher & Williams, 2013; Gam & Banning, 2011; Kennedy & Terpstra, 2013; Leerberg et al., 2010). However, few researchers reported introducing specific sustainability practices in product development and patternmaking courses. For example, Hall and Orzada (2014) reported

[1] Department of Design, University of North Texas, Denton, TX, USA
[2] Department of Family and Consumer Sciences, Illinois State University, Normal, IL, USA

Corresponding Author:
Hae Jin Gam, Department of Design, University of North Texas, 1155 Union Circle #305100, Denton, TX 76203, USA.
Email: haejin.gam@unt.edu

implementing zero-waste patternmaking in the draping course. However, this was possible because of the curriculum revision process. Two other researchers (Pasricha & Kadolph, 2009) also reported developing a unit within the technical garment to address sustainable product development, but they did not include the zero-waste design concept. Hall and Orzada (2014) stated that while designers consider mainly supply chain and material choices, the consideration of avoiding or reducing textile waste was not in their awareness, though it is an important issue. Gam and Banning (2011) also stated that students could obtain a broader idea of sustainability by including a zero-waste design approach when participating in a sustainability-themed fashion show. Gam and Banning (2011) and Pasricha and Kadolph (2009) recommended introducing a zero-waste design approach to design students within the existing curriculum rather than as a stand-alone course.

Runnel et al. (2017) gathered data from seven major Chinese and Bangladeshi garment factories, which produced in total 250 million garments per year, and estimated that more than 25% of material (including defective fabric, extra fabric due to production inefficiency, and cutting scraps) was wasted during the manufacturing process. Conventional pattern pieces for most apparel items have irregular shapes that cannot be laid without gaps between them. As a result, the pattern-cutting process generates an average of 15%–20% waste (Rissanen, 2013). With motivation from the sustainable fashion movement, fashion designers such as Holly McQuillan, Timo Rissanen, and Yeohlee Teng have suggested that textiles should not be wasted at the stage of patternmaking. Townsend and Mills (2013) define this zero-waste strategy:

> Zero-waste pattern cutting (ZWPC) is the process of eliminating the usual 15–20% loss of fabric at the cutting stage by creating a pattern or several patterns integrated in one, using the entire width and a predetermined length of fabric, thereby creating a pattern that completely fits the dimensions of the fabric. (p. 104)

This newer perspective on design requires new ways of thinking about the design process and the look of the final product. However, this concept has not been a part of traditional design education (Hall & Orzada, 2014). Effective teaching strategies, therefore, should be developed to prepare a new generation of designers to use the zero-waste design concept.

Project-based learning (PjBL) has been utilized as an active learning approach that encourages students to effectively learn new knowledge (Larmer et al., 2015). PjBL facilitates the creation of an environment, where students can learn in real-world settings through collaborative learning, be motivated to inquiry-based engagement (Wiek et al., 2014), be centered, and be self-directed (McGibbon & Van Belle, 2015). Studies suggest that PjBL is an effective tool for teaching sustainability concepts in existing courses (Jollands & Parthasarathy, 2013; McGibbon & Van Belle, 2015).

In an effort to enhance students' knowledge of sustainability practices, the purpose of this study was to develop and evaluate class projects in which students practiced the concept of zero-waste design, so they would be more aware of fabric waste generated during the design process. As students are more exposed to sustainable design principles, including zero-waste design, we hope they will make proactive rather than reactive decisions when creating sustainable designs in the future.

Review of Literature

PjBL

Using a project as a replacement for the typical unit of instruction was originally suggested by Kilpatrick (1988). Kilpatrick defined PjBL as the use of purposeful activity and proceeding in a social environment for the utilization of learning. Kilpatrick also indicated that successful project design should include an effective purpose and address a social situation. According to Lenz et al.

(2015), project development should include production and complexity; PjBL itself should be achieved through a multiple process engagement that includes inquiry, demonstration, and applying knowledge and inspiration.

Designing a project is not a straightforward process; continual reflection should take place during the design and revision process. The project should be a tool for teaching content, while including a sustained inquiry process, the creation of a product, and an authentic connection to the real world (i.e., solving a real-world problem, meeting a design challenge, exploring an abstract question, conducting an investigation; Larmer et al., 2015). Larmer et al. (2015) suggested the project design process includes (a) considering the context, (b) generating an idea, and (c) building the framework. From this process, students will be more engaged by a topic or tasks, enhance their self-confidence, and broaden their perspective, and instruction will be more effective for deeper learning (Brookfield, 2017). PjBL strategies have been actively employed in engineering, architecture, and business curriculum (Larmer et al., 2015).

Instructors in various programs have developed projects to address numerous issues such as incorporating a social media project to teach collaborative learning in higher education (Lapolla, 2014); developing PjBL activities throughout an undergraduate program to encourage students to increase community participation, explore sustainability challenges, engage in environmental justice, and finally conduct a collaborative research project (Wiek et al., 2014); and developing multiple projects to improve students' understanding of sustainability within chemical engineering programs (Jollands & Parthasarathy, 2013).

Instructors who engaged in developing PjBL concluded that this teaching strategy was effective in developing professional skills, such as focusing on customers, working in a group setting, and critiquing peers through an engaging real-life problem-solving project (Lapolla, 2014); increasing interpersonal competencies and transdisciplinary work experience, which can be difficult to obtain through lecture-based learning (Wiek et al., 2014); and improving students' understanding of sustainability to "clarify the complexity and breadth of sustainability issues that apply to process design decisions" (Jollands & Parthasarathy, 2013, p. 5064).

However, there are challenges in implementing PjBL in higher education. Jollands and Parthasarathy (2013) indicated that the effectiveness of PjBL depended on the discipline and the problem type. Thus, selecting an appropriate project topic is "critical to achieving the right level of complexity" (p. 5054). In addition, developing projects may need more work "to ensure learning outcomes across the full range of competencies" (p. 5053). Other challenges in incorporating PjBL into coursework include intermittent interactions, student turnover, accommodating academic schedules, receiving necessary institutional support, and the need for longer contact hours compared with lecture-based courses (Wiek et al., 2014). To overcome these challenges, reflecting on past lessons and supporting faculty training to select interesting and relevant topics were recommended (Larmer et al., 2015; Wiek et al., 2014).

In summary, designing and implementing a new project (practical activities) as a curricular activity has helped students to improve their knowledge, problem-solving and communication skills, and competency. Therefore, PjBL was selected as a teaching tool to develop and evaluate class projects in which students applied the concept of zero-waste design. We hoped that, as a result of their experience, students would be more aware of fabric waste generated during the design process.

Zero-Waste Design

The current waste management system in apparel manufacturing has focused largely on reduce, reuse, and recycle rather than on eliminating waste altogether (Fletcher, 2013). However, these reduce, reuse, and recycle strategies have been criticized by inefficient industry systems, focusing on one small part of the system as a short-term solution rather than the whole over the long term; these

strategies have been suggested as transitional (Fletcher, 2013; Rissanen, 2005). As a holistic approach to sustainability, designers should not look at waste as an inevitable by-product; instead, designers should create "a future where we produce no waste at all" (Fletcher, 2013, p. 108).

Innovative design. The zero-waste design concept as an effective material usage method has appeared as part of sustainable product manufacturing. This concept not only emphasizes conserving materials but also highlights the creativity needed to be innovative. Fletcher (2013) identified methods of achieving zero-waste fashion design. The first method is using knitting techniques such as seamless knitting and whole garment knitting. With this method, the entire piece is made three-dimensionally directly on the knitting machine instead of making separate parts and assembling them. The product thus has significant energy-saving potential and reduces labor costs while eliminating fabric waste (Fletcher, 2013). The second method to achieve zero-waste designs can be achieved in two different ways: one is creating patterns that use the entire width of fabrics and the other is reclaiming the use of scraps. The term zero-waste used in this article is addressing inefficiency in fabric usage during the patternmaking process and attempting to waste no fabric at the design stage (Rissanen & McQuillan, 2016).

While the concept of zero-waste design is new to modern fashion design, the principles of the practice have been in use for centuries around the world. Many traditional garments, such as the Japanese kimono, Roman chiton, and Indian sari, reflect zero-waste design; the fabrics used to make these garments were considered valuable (Rissanen & McQuillan, 2016). After centuries of clothing tailored to closely fit bodies, zero-waste clothing appeared again in 1919 with the futurist activist Ernesto Thayaht, who created a jumpsuit called "Tuta," thanks to its "T" shape (Rissanen & McQuillan, 2016). In contemporary times, an increasing number of fashion designers have implemented zero-waste design to eliminate fabric waste (Rissanen & McQuillan, 2016).

Designers embrace sustainability. Even with modern computer technology, contemporary fashion-making methods waste about 15%–20% of the total fabric used during the cut and sew process. However, unsustainable clothing production and manufacturing processes were not considered the designers' responsibility in the past (Rissanen, 2005). Inspired by preindustrial societies where fabrics were treated as precious resources, some fashion designers, such as Rissanen (2005), investigated "the potential of waste elimination within contemporary fashion industry" (p. 1) and suggested a reorganization of the current design process hierarchy by treating patternmaking as integral to the design process.

The zero-waste design approach provides designers tool to take charge of creating sustainable designs, while this reorganization should be an opportunity for innovative fashion design (Rissanen, 2005). "Basic shape manipulation and its relationship to the body are necessary for developing an understanding of creative pattern cutting methods and this can lead to a logical progression into zero-waste cutting" (Townsend & Mills, 2013, p. 105). Creative pattern cutting can yield high-end fashion garments, and a zero-waste design approach provides an excellent opportunity for achieving creative cutting (Townsend & Mills, 2013). James et al. (2016) conducted interviews of current designers and pattern cutters and also agreed that zero-waste design can take the lead in creative design. It suggests further collaboration between design and production (James et al., 2016) and a holistic design approach (Townsend & Mills, 2013) to achieve zero-waste design.

ZWPC approaches. Various methods have been used to achieve zero-waste design in fashion and have been defined and summarized by Carrico and Kim (2014), Cho and Lee (2015), and McQuillan and Rissanen (2011).[1] Carrico and Kim (2014), who examined McQuillan's zero-waste practices, pointed out that embracing unpredictability during the zero-waste patternmaking process was challenging as designers also need to focus on aesthetics and functional aspects of design. However, the

authors also found that engaging in the whole design process was ultimately satisfying and concluded that this experimentation was valuable not only for reasons of sustainability but also because it provides a new creative patternmaking challenge. Furthermore, the authors indicated that while some zero-waste designs can be worn by different sizes, mass-production realization of zero-waste patterns as grading patterns for production was limited. Carrico and Kim (2014) additionally criticized that "in an effort to eliminate scrap fabric waste, excess fabric may remain within the garment unnecessarily" (p. 63).

Cho and Lee (2015) examined jigsaw puzzle, subtraction cutting, and layer methods as zero-waste fashion design. The three methods were evaluated by two categories, creativity (creation ability, idea visualization, and sense of aesthetics) and design integration (comprehension, analytic thinking, and user consideration). The authors assessed the difficulty level based on comprehension, application, and accessibility. While the layer method was considered the most manageable (easy-to-use) technique, the subtraction cutting and jigsaw puzzle methods were considered unfamiliar and less approachable. Cho and Lee (2015) found that once students were exposed to these techniques, they were willing to expand their usage of the techniques and that their awareness of their role in eliminating textile waste increased.

ZWPC limitations. While previous researchers indicated that working within a zero-waste design approach reinforces a different way of thinking and thus fosters creativity (Rissanen & McQuillan, 2016), they also enumerated some limitations and challenges of practicing zero-waste fashion design. As consideration of textile width is crucial in zero-waste fashion design (Rissanen, 2013), "changes in fabrics later in the process could have significant implications on design and time management of the process" (James et al., 2016, p. 144). In addition, "the unpredictability of pattern shapes is the primary obstacle to eliminating fabric waste" (Rissanen, 2005, p. 3), and the final look is not completely predictable before production is finished (Carrico & Kim, 2014). Another challenge defined by Saeidi and Wimberley (2018) is that zero-waste fashion design is more time-consuming than the conventional fashion design process for reducing waste of resources, and some zero-waste fashion design methods (e.g., tessellation) require significant mathematical work and calculation. However, even with these limitations, teaching zero-waste fashion design will be worthy as there will be positive outcomes from students understanding the effective use of resources to realize sustainability within the complexity of the fashion industry.

Teaching Procedure

Knowledge of the patternmaking process is a crucial competency in the apparel industry; therefore, fashion design programs contain a variety of product development and patternmaking courses. In this study's product development and patternmaking courses, however, sustainability practices were not addressed as learning objectives. As a result, sustainability themes had not previously been introduced into either course through direct instruction or assigned projects. The purpose of this study was to develop and evaluate class projects that incorporated the zero-waste design concept in two levels of existing design courses in an effort to increase students' awareness of sustainable fashion design practices and their creativity.

Zero-Waste Design Project Development

Guided by the PjBL framework, zero-waste design projects were developed for two courses: product development and patternmaking. During the first stage of project development, the context of the problem to be addressed through the assignment was considered (Larmer et al., 2015). The defined context of the problem was that the conventional pattern-cutting process generates on average

15%–20% of new fabric waste (Rissanen, 2013), but employing zero-waste design can significantly reduce the loss of fabric at the design stage. It was also noted at this stage that a zero-waste design project can be a "creative patternmaking challenge by uniting the roles of designer and pattern making in a holistic approach to creating garments, considering aesthetics and function simultaneously" (Carrico & Kim, 2014, p. 58). This newer perspective on design would help students develop creativity while considering sustainability.

Ideas were generated in Stage 2 of the project development, including the concept that zero-waste design projects could be implemented into two existing courses (Larmer et al., 2015). The first course was product development, chosen because instructors wanted to evaluate feedback from students with beginning sewing skills. The second selected course was patternmaking, chosen because students were focused on developing design competencies and had more advanced skills to apply creative concepts to designs. In both courses, students learned how to work with patterns. Students in product development used commercial patterns, while patternmaking students used patterns they made themselves.

In the third stage of project development, the framework was built by writing the actual assignments that students would use to learn zero-waste design (Larmer et al., 2015). With consideration for established course learning outcomes and semester schedules, it was determined that the project should fit into two or three class periods and should provide students the opportunity to apply knowledge and skills that they previously learned in that class. Projects amounted to approximately 10% of students' overall grade in each course and were assessed based on learning outcomes for each course.

Each project started with an introductory lecture that addressed current problems in the fashion industry, including the amount of waste generated. Discussions of pre- and postconsumer waste and fast fashion were provided as justification for the project. Various approaches to zero-waste design were also discussed. Each project was geared to the level of skill students had reached in each course at the time the zero-waste design project was initiated. Instructors also considered difficulty level, time constraints, and course objectives when selecting appropriate zero-waste design patterns for projects. Two patterns were adopted from Rissanen and McQuillan (2016). The pant pattern was selected for both courses, while a zero-waste coat pattern (p. 93) was selected as a second pattern to be used in the patternmaking course. Patterns were selected by considering the project duration and difficulty.

Project Implementation

The zero-waste design project was introduced in two fashion courses: product development and patternmaking. Product development is a required course for both fashion design and fashion merchandising students in the program and is a prerequisite for a senior-level apparel product analysis course required of all students. Product development is also a prerequisite for the patternmaking course. Projects for the semester-long course include a sample book of sewing skills, a below-the-waist garment such as a skirt, and an above-the-waist garment such as a tailored shirt or unlined jacket. The zero-waste design project was implemented after students completed their sample book and below-the-waist projects.

In the patternmaking course where students learn skirt, pant, and blouse pattern drafting and manipulation, two zero-waste projects were introduced. A zero-waste pant pattern was introduced after students learned pant pattern drafting. A zero-waste coat pattern was introduced after students learned blouse pattern drafting. Both designs had simple lines but used different approaches than what students had previously learned to design and construct similar garments. As ZWPC uses the entire fabric width when designing a garment, students were free to use different sizes of fabrics in achieving their desired final look. The instructor also explained the different outcomes by using different fabric dimensions.

Method

According to Chandrasekaran and Al-Ameri (2016), "the assessment [of the project] is the process of gathering and interpreting evidence to make judgments about student learning" (p. 24). As the objectives of the projects were increasing students' awareness of generating fabric waste and motivating students to incorporate sustainable design in their work through the zero-waste design project, two sets of instruments were developed to observe students' learning outcomes. Data were collected before and after the zero-waste design project implementation in each course during three consecutive semesters. The project was implemented and evaluated 3 times in product development and twice in patternmaking. It was not evaluated a third time in patternmaking because by the third semester, all students enrolled had participated in the project and completed the evaluation when taking product development.

In the preproject survey, students were first asked whether they previously had taken a sustainability course. Next, questions related to students' interest in sustainable living and fashion were asked. These questions were adapted from Wu et al. (2013), who investigated the consumer group who participated in the Great American Apparel Diet for their motivation. Identified themes under environmental motivation were used for questions in this study. Questions related to students' consideration of negative impact from fashion to environment were added; these questions were developed based on the statement of describing the current problems of apparel production and consumption (Ruppert-Stroescu et al., 2015). These items were measured using a 5-point Likert-type scale ranging from *strongly disagree* (1) to *strongly agree* (5). In addition, questions gauging their awareness of fabric waste generated during the apparel production process and their efforts to reduce fabric waste were asked, as well as questions about their previous experience with zero-waste design and sustainability practices. The postproject survey repeated three categories: (a) interest in sustainable living, sustainable fashion, and environmental impact from the fashion industry; (b) their awareness of fabric waste generated during the apparel production process; and (c) their efforts to reduce fabric waste from preproject survey to see whether completion of project would influence their scores in these categories. In addition, items asked their opinions of the zero-waste design projects. Most of the questions were developed by instructors to see whether the project achieved the learning goals, and wordings (e.g., hinder, enhance, creative) were adopted from Townsend and Mills (2013), who narrated the experiential learning process of zero-waste approaches to cutting. These questions used a 5-point Likert-type scale ranging from *strongly disagree* (1) to *strongly agree* (5) and also included space for students to provide open-ended feedback about the zero-waste design projects.

Participants

Participants in the study were students enrolled in the product development course and the patternmaking course at a university in the Midwestern United States. Before and after project implementation, students were informed about the project. Another instructor who did not teach the course explained that participation was voluntary and administered the process of obtaining consent of participation. The project was approved by the university's institutional review board.

Data Analysis

Descriptive analyses and a series of independent *t* tests were used to compare means in the two types of design courses. To determine dimensionability of sustainable fashion and lifestyle, exploratory factor analysis was performed. This technique is frequently used to identify the underlying factor structure to explore the interrelations among a set of variables that have not been fully validated

Table 1. Demographic Characteristics of the Sample.

Variables	Description	Frequency[a]	%[b]
Gender	Female	77	98
	Male	1	1
	Other	1	1
Year in school	Freshman	2	1.01
	Sophomore	14	71.7
	Junior	36	45.56
	Senior	27	34.18
Major	Design	20	54.6
	Merchandising	43	4.3
	Both major	11	10.6
	Other	5	2.0

[a,b]Some total counts and percent values may not be equal to the sample size and 100% due to missing data.

(Child, 1975). Exploratory factor analysis generated two factors: *interest in sustainable living and fashion* and *considering negative impact from fashion to environment*.

To test the impact of the project completion between two course levels, a mixed 2 × 2 analysis of variance (ANOVA) was used. In addition, a grounded theory approach was used to conduct theoretical coding of students' written responses (Strauss & Corbin, 1998). To identify themes in written comments, responses were analyzed and categorized separately by researchers for this study. Overall, themes were then identified.

Results

Sample and Descriptive Analysis

Of the 91 students enrolled, 85 students participated in the presurvey and 83 students participated in the postsurvey. Because we were collecting data from three consecutive semesters, if students participated in the same survey in other classes, their later responses were removed. In addition, if students did not complete the survey, their responses were removed. After cleaning the data, a total of 79 presurvey responses and 72 postsurvey responses were deemed usable. A profile of participants is included in Table 1, while information relating to student participation in the pre- and postsurvey from each course is included in Table 2.

Among 79 responses to the presurvey, 34 students (43%) indicated that they had taken a course that focused on sustainability. Thirty-seven students (46.8%) indicated that they had heard of zero-waste design previously, and a majority of them had heard about sustainability as part of other courses in the program ($n = 28$). Forty-five students (57%) answered they considered sustainability aspects when they created garments.

In the postsurvey, students' opinions about the project were collected using questions based on a 5-point Likert-type scale (Table 3). Students agreed that the project helped them (a) to learn about sustainable design ($M = 4.22$, $SD = 0.84$), (b) to learn about the concept of zero-waste design ($M = 4.23$, $SD = 0.92$), and (c) to become more aware of the different environmental issues regarding apparel production ($M = 4.36$, $SD = 0.86$). In addition, they disagreed that the zero-waste design approach hinders the creative design process ($M = 2.85$, $SD = 1.18$). However, students somewhat agreed with the following: That the project helped to enhance their creative design process ($M = 3.85$, $SD = 0.91$), that they would practice zero-waste design in the future ($M = 3.78$, $SD = 1.21$), and that they would buy ($M = 3.77$, $SD = 0.79$) or wear ($M = 3.53$, $SD = 1.17$) zero-waste design. In addition, results of independent t tests showed that students in the patternmaking course reported

Table 2. Frequency Distribution of Participants of the Study.

	Product Development		Patternmaking	
Semester	Presurvey	Postsurvey	Presurvey	Postsurvey
Fall 2017	21	13	11	11
Spring 2018	14	13	8	9
Fall 2018	25	26	N/A	N/A
	60	52	19	20

Note. N/A = not applicable.

Table 3. Means of Students' Opinions About Zero-Waste Design Projects.

	Both		PD ($n = 53$)		PM ($n = 20$)		
Item	Mean	*SD*	Mean	*SD*	Mean	*SD*	*t*-Test
The zero-waste design project helped me to learn about sustainable design.	4.22	0.84	4.08	0.89	4.60	0.50	−2.47*
I have become more aware of the different environmental issues regarding apparel production.	4.36	0.86	4.34	0.88	4.40	0.82	−.27
I think the zero-waste design approach hinders the creative design process.	2.85	1.18	2.87	1.11	2.80	1.36	.22
I think the zero-waste design approach enhances the creative design process.	3.85	0.91	3.68	0.85	4.30	0.92	−2.71**
The zero-waste design project helped me to learn about the concept of zero-waste design.	4.23	0.92	4.13	0.96	4.50	0.76	−1.54
I would like to practice zero-waste design when I design in the future.	3.78	1.21	3.57	1.16	4.35	0.75	−2.79**
I will wear the project(s) that I made.	3.53	1.17	3.45	1.20	3.75	1.07	−.97
I will buy clothing that is made using a zero-waste design approach.	3.77	0.79	3.60	0.74	4.20	0.77	−3.03**

Note. PD = product development; PM = patternmaking.
*$p < .05$. **$p < .01$.

Table 4. Factor Analysis of Sustainable Living and Sustainable Fashion.

Factors	Factor Loading
(1) Interest in sustainable living and fashion (eigenvalues = 4.52; % of variance = 56.53; Cronbach's $\alpha = .88$)	
I am interested in green/eco-friendly trends	.77
I am interested in reducing my carbon footprint	.74
I am interested in re-/upcycling	.65
I want to avoid a wasteful lifestyle	.77
I am interested in living more sustainably	.88
I am interested in becoming a sustainable fashionista or fashionisto	.76
(2) Considering negative impact from fashion to environment (eigenvalues = 1.06; % of variance = 13.18; Cronbach's $\alpha = .66$)	
I think my apparel making has the potential to negatively influence the natural environment	.93
Fashion apparel consumerism has the potential to negatively influence the natural environment because the consumption of apparel depletes the earth of both renewable and nonrenewable natural resources, creates unmanageable quantities of solid waste, and emits dangerous substances into the air, water, and land	.70

Table 5. A Mixed 2 × 2 ANOVA.

		Presurvey		Postsurvey		Within	Between
Variable	Course	Mean	*SD*	Mean	*SD*	*F* Value	*F* Value
Interest in sustainable living and fashion	PD ($n = 52$)	25.13	3.65	26.33	3.20	$F(1, 70) = 8.38$**	$F(1, 70) = 5.84$*
	PM ($n = 20$)	27.05	2.74	28.05	2.11		
	Total	25.67	3.51	26.81	3.03	$\eta_p^2 = .107$	$\eta_p^2 = .077$
Considering negative impact from fashion to environment	PD ($n = 52$)	7.67	1.61	8.00	1.51	$F(1, 70) = 0.78$	$F(1, 70) = 10.84$**
	PM ($n = 20$)	8.75	1.07	8.85	1.04		
	Total	7.97	1.56	8.24	1.43	$\eta_p^2 = .011$	$\eta_p^2 = .134$
Consciousness about generating fabric waste	PD ($n = 52$)	3.43	1.12	4.06	0.84	$F(1, 70) = 4.03$*	$F(1, 70) = 14.63$**
	PM ($n = 20$)	4.40	0.688	4.45	0.76		
	Total	3.70	1.11	4.17	0.83	$\eta_p^2 = .055$	$\eta_p^2 = .175$

Note. ANOVA = analysis of variance; PD = product development; PM = patternmaking.
*$p < .05$. **$p < .01$.

higher means in 4 items: (a) zero-waste design helped them to learn about sustainable design ($t = -2.47$, $p = .016$), (b) the zero-waste design approach enhanced the creative design process ($t = -2.71$, $p = .008$), (c) they would like to practice zero-waste design when they design in the future ($t = -2.79$, $p = .007$), and (d) they would buy clothing that is made using a zero-waste design approach ($t = -3.03$, $p = .003$).

Factor Analysis

Items regarding students' interest in sustainable living, sustainable fashion, and environmental impact from the fashion industry were reduced using principal component analysis with varimax rotation. To determine underlying dimensions of each scale, minimum eigenvalues of 1.0 and item factor loadings above .65 but not higher than .30 on the other factors (Kline, 1994) were considered valid. A Cronbach's α of .70 was considered acceptable to retain an item in a scale for both independent and dependent variables. Eight items in sustainable living and sustainable fashion were reduced to two factors while all items were retained. For all factors, factor loading ranged from .65 to .93 (Table 4).

Comparing the Impact of Project Completion Between Two Course Levels

A mixed 2 × 2 ANOVA was conducted to see whether there were differences between students in two courses in the pre- and postsurvey (Table 5). There was a significant difference between pre- and postproject in interest in sustainable living and fashion, $F(1, 70) = 8.38$, $p = .005$, $\eta_p^2 = .107$, and a significant difference between the two courses, $F(1, 70) = 5.84$, $p = .018$, $\eta_p^2 = .077$. While there was no significant difference between pre- and postproject in *considering negative impact to environment*, $F(1, 70) = 0.78$, $p = .381$, $\eta_p^2 = .011$, there was a significant difference between the two courses, $F(1, 70) = 10.84$, $p = .002$, $\eta_p^2 = .134$. In addition, there was a significant difference between pre- and postprojects in *consciousness about generating fabric waste*, $F(1, 70) = 4.03$, $p = .049$, $\eta_p^2 = .055$, and a significant difference between the two courses, $F(1, 70) = 14.63$, $p = .00$, $\eta_p^2 = .175$.

Qualitative Responses

In the preproject survey ($n = 79$), students were asked about their efforts to reduce fabric waste. Students indicated four methods. Thirty-three students (41.8%) indicated that they used strategic

pattern placement and effective material usage as a way to reduce fabric waste. Seventeen students (21.5%) indicated that they saved scraps from pattern cutting for future use. Among them, eight students listed both (effective pattern placement for more saved fabric) methods. In addition, four students said they tried to use secondhand or donated fabrics, and two students said repairing clothes was a solution to reduce fabric waste.

The same question was asked in the postproject survey ($n = 72$). Students' responses were similar to answers in the preproject survey. Twenty-nine students (40.3%) indicated that strategic pattern placement was a way to reduce fabric waste, and 24 students (33.3%) indicated that they saved scraps from the pattern-cutting stage for future use in other projects. Some students ($n = 21$) listed both methods (effective pattern placement resulting in more fabric to be used in the future). In addition, four students indicated that they tried to alter their designs or patterns to reduce fabric waste. Six students indicated that they tried not to waste any fabric at all when cutting out projects.

In the postproject survey, students' opinions about the limitations of zero-waste design were collected. Twenty-five students (34.7%) listed design restrictions from the zero-waste design approach. About a quarter of students ($n = 18$) indicated that styles and fit were limitations of zero-waste design. Eight students said zero-waste design required more thought to execute. Some students saw the zero-waste design approach as restrictive, while some students considered it an opportunity. Nine students found no limitations in the zero-waste design approach, and one student commented, "The limitations are that you are confined to the amount of fabric you have and try to use it all so there's no waste. This could be tricky but overall doable."

Finally, students were asked about their experiences with the zero-waste design project. Eighteen students (25%) indicated that they liked the project because they learned how to be resourceful to prevent fabric waste. Twelve students (16.7%) liked the project because they learned the new concept and approach in fashion design. Eight students liked the project because they liked the design of the garments they created. Six students liked the project because they practiced creativity. Another six students liked the project because zero-waste design used different construction methods (some said it was easy to make). The following are selected representative comments of positive experiences:

- "I liked that it is zero waste and figuring out how to construct it was fun" (product development class).
- "I liked that it taught us to be mindful of how we sew and how much fabric to use while doing so. I now realize how important it is to create as little waste as possible because it really does add up" (product development class).
- "I love zero-waste design because of the creative shapes that are created with patterns" (patternmaking class).
- "I liked the challenge of being creative within specific confines, which made the project involve more problem solving" (patternmaking class).

There was also a negative feedback. Even though they liked learning the zero-waste design approach, 12 students (16.7%) were critical about the look of their project. Six students complained about its difficulty to execute, and three students indicated that they did not like the project because of the limitations to zero-waste design. The following are selected representative comments of negative experiences:

- "I like how it's better for the environment however during the project, for example, I didn't like the visual design/fit of the finished garment" (product development class).

- "The pattern was harder to follow, it was difficult to see the bigger picture at times" (product development class).
- "It is definitely more difficult/time-consuming to produce" (patternmaking class).

Discussion

The zero-waste design approach is very different than conventional patternmaking and cutting; thus, the practice presents both challenges and learning opportunities for students. From the results of pre- and postsurveys, we learned that the project was helpful in teaching students the zero-waste design concept, and they became more aware of the fabric waste they were generating. Students' written comments about their experiences support these findings, and students suggested that the zero-waste project positively influenced their own sustainability practices. Furthermore, after project completion, more students employed more than one strategy to reduce fabric waste.

Additionally, we found there were differences in terms of students liking the projects and their interest in sustainable living and fashion between the two different course levels. Finally, while zero-waste design projects can be introduced in different levels of design courses, it is suggested that implementing these projects in patternmaking courses, when students have gained more fashion design skills, could be more effective. Students said they liked the idea of zero-waste design, its creativity, and its unique silhouette, but they did not like it in terms of fit and flexibility in creating different sizes. Students also indicated little choice in style variety and tailoring as limitations of the zero-waste approach. Students complained about the unpredictability throughout the zero-waste design process, a finding supported by Carrico and Kim (2014), who said, "The process of creating zero-waste garments is unpredictable while also providing a tremendous design challenge" (p. 63). Some students indicated that the project was challenging for them. The differences in feedback could be due to the varying abilities and motivation levels of the students (Jollands & Parthasarathy, 2013). Also, "understanding the complexity of sustainable fashion issues can be overwhelming and a barrier for fashion designers" (Kozlowski et al., 2019, p. 1). Townsend and Mills (2013) pointed out that familiarity with conventional cutting methods could be a challenge when learning zero-waste design. Ellmers (2017) suggested that letting students "draw generalizations from their projects supports them to connect thinking about their projects with thinking about practices" (p. 77).

Limitations and Future Research Directions

While students agreed that the zero-waste design project helped them to consider sustainable design, their answers for approaches to reducing fabric waste were not significantly changed (e.g., effective pattern placement, saving scraps for future use). Thus, future researchers may implement different zero-waste fashion design methods (e.g., jigsaw puzzle method) into project development for encouraging students to implement creative solutions. Students' style preferences also affected their project experience (e.g., if students liked loose and comfortable styles, they were more likely to enjoy the zero-waste design project). Selecting styles through discussion with students or giving more style options to students and allowing them to select their preference is recommended, but this option could require more instructional preparation.

Jollands and Parthasarathy (2013) suggested that "the most effective pedagogy for students to learn about sustainable development was a community-based project with collaboration of multiple learners as well as use of a constructive-learning pedagogy" (p. 5053). Eike et al. (2018) implemented service learning in an apparel course, where students participated in mending and alteration tasks through a community-based project. Eike et al. (2018) concluded that service-learning

experiences benefited personal and professional student growth. Thus, developing and evaluating a community-based project that implements a zero-waste design approach is recommended.

The projects developed in this study had more impact on students' enhanced consciousness toward generating fabric waste than increasing their awareness about the negative impact from fashion to environment. A future study should address the limitation by developing and evaluating projects encouraging student awareness of these issues. In addition, the projects developed and implemented in this study were based on the institutions' established curriculum, which did not include sustainability components. Institutions that have implemented sustainability components into curriculum, particularly specific courses on sustainable design (which may even include concepts such as zero-waste design), could share their own best practices with other universities.

Another limitation of this study is the assessment method. This study used students' own assessment of their work (PjBL). According to Benett (1993), "Students have their own conceptualization of supervised work experience and their conceptualization imposes a structure on their experience and on how they make sense of it" (p. 86). However, Benett (1993) also stated that "The validity of students' self-assessments of their performance at the workplace depends on whether students have internalized these standards (and the underpinning values) and are able to assess their performance against these 'objective' criteria and standards" (p. 85). When the project was introduced, current problems in the fashion industry were explained and discussed with students as project justification, and it is hoped that students for this study understood the objective of the project. Finally, questions used in this study were not from theory-driven studies; thus, measures were not tested for validity and did not report reliability. Although we attempted to overcome the limitation of using students' self-reporting as assessment and developing questions from nonvalidated scales, adding other assessment methods such as comparing project grades, utilizing standardized tests to evaluate students' increased knowledge and awareness, or examining whether the zero-waste project could enhance students' creativity or spatial visualization skills are suggested for future researchers. Measuring longitudinal impact would be equally valuable.

Conclusion

Achieving an increased number of sustainable apparel products will require new ways of thinking about design. Zero-waste design is an option that emphasizes creativity to create solutions. Based on this study, we suggest that educating students about sustainable design options influences positive changes in incorporating sustainable practices. Developing a new sustainable fashion design course could be an ideal solution of teaching sustainability to current fashion design students. However, including one more course in the current curriculum may not be realistic for many programs. Therefore, we developed zero-waste design projects in existing fashion design courses and concluded that the projects encouraged students to be aware of generating fabric waste while teaching the original objectives of courses.

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ORCID iD

Hae Jin Gam https://orcid.org/0000-0003-0318-2463

Note

1. Representative methods in zero-waste fashion design are (a) tessellation or layer technique: cutting one shape, usually thin strips, and then assembling these pieces to form garments; (b) jigsaw puzzle method: design patterns to interlock perfectly on the fabric; and (c) minimal cutting: achieving design garments through draping and minimal cuts and embracing the concept of designing with the fabric width.

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Author Biographies

Hae Jin Gam, PhD, is an associate professor in the Department of Design at the University of North Texas. Her research interests include sustainable development in the apparel and textile industry, consumers' eco-friendly purchasing behavior, creative and sustainable apparel product development, and examining effective teaching.

Jennifer Banning, PhD, is an associate professor in the Department of Family and Consumer Sciences at Illinois State University. Her research interests include sustainability, the social, cultural, and historical aspects of dress, and the scholarship of teaching and learning.