Teaching virtual apparel technology through industry collaboration: an assessment of pedagogical process and outcomes

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Abstract:

Graduates of apparel programmes are entering a workforce that requires the use of emerging technologies that are relevant to performing job requirements. Among apparel companies, virtual technologies are increasingly being used in the product development process. Virtual technologies are also becoming important in higher education, as programmes seek to incorporate them into the teaching and learning environment. The two-fold purpose of this study was to develop an approach to teaching virtual technology that is apparel industry-specific, and to evaluate outcomes using a framework of learner-centered curriculum design combined with Kirkpatrick's [(1994). Evaluating training programs. San Francisco, CA: Berrett-Koehler] training evaluation model. A mixed-methods research design was employed, beginning with a presentation to students followed by two weeks of in-class training. Assessment of outcomes was conducted via pre- and post-test comparisons and in-depth interviews. Results indicated improvement in students' attitudes toward the technology and skills important to using it. Findings contribute to the growing literature on teaching virtual technology.

Keywords: 3D | pedagogy | technology | virtual programming

Article:

Students are preparing to enter a workforce that requires they not only be knowledgeable in the use of applied technologies, or those specific technologies that are directly relevant to performing job requirements, but that they are capable of learning and implementing new technologies on a regular basis (Wilen-Daugenti, Citation2009). Moreover, firms expect that their employees will have some degree of industry-relevant technology knowledge and skills, and value experience with such technology when making hiring and promotion decisions (Noguera & Watson, Citation2004). Within the apparel industry, computer applications and software, such as AutoCAD, Illustrator, and MS Excel, are frequently used for product development and then filtered through the supply chain by way of a data management system (Suleski & Draper, Citation2011). However, it is the

3D or ‘virtual’ technologies that are fast becoming the requisite technologies among apparel companies, especially the use of 3D printing and virtual prototyping (De Silva, Rupasinghe, & Apeagyei, Citation2019). The latter technologies in particular offer companies faster and more accurate approaches to product prototyping and testing, as well as reduced waste, as there is no need to produce test garments out of physical materials (Papahristou & Bilalis, Citation2016). As virtual technologies become the new industry normal, graduates of apparel programmes will be expected to know how to use them to maximise efficiencies while minimising costs (Zhang & Huang, Citation2014).

At the same time that virtual technologies are becoming important to the industry, they are also becoming important in higher education, as programmes seek ways to incorporate them into the teaching and learning environment (Chang, Citation2014; Park, Kim, & Sohn, Citation2011). Thus, the two-fold purpose of this study was to develop an approach to teaching virtual technology that is apparel industry-specific, and to conduct a preliminary evaluation of the resulting outcomes to better understand the needs of apparel students as virtual technology learners. As it is still early in the adoption process, best pedagogical practices relative to virtual technology have yet to be identified and fully articulated in the literature (Baytar, Citation2018; Kwon & Kim, Citation2002). The present study seeks to address this void.

Background

To consider the extent to which virtual or 3D technologies have been examined within the teaching and learning context, literature that offers insight into how students learn 3D in apparel programmes was reviewed. Although such literature is still in its nascency within the clothing and textiles field, there are several studies that offer a starting point. In this section, Kirkpatrick’s Training Evaluation is discussed as a conceptual framework of the study. In addition, literature is discussed relative to the types of technologies examined, as well as studies pertaining to the particular 2D to 3D skills that can be enhanced through activities designed to develop students’ competencies in virtual technology.

Conceptual framework

The conceptual framework employed in this study is based on the Training Evaluation model developed by Kirkpatrick (Citation1994), as it provides a systematic model for investigating students’ learning outcomes and training evaluation (Bates, Citation2004). Kirkpatrick’s model is designed to determine aptitude derived from training and educational programmes based on four levels of criteria, including: (1) reaction, or the response to the training event (e.g. satisfaction, engagement); (2) learning, or the degree to which objectives for training were met (e.g. knowledge, skills, abilities); (3) behaviour, which refers to the extent to which knowledge and skills are applied; and (4) results of the training for achieving broader organisational or training goals (Kirkpatrick, Citation1994). Figure 1 depicts the four levels of the process.

The Kirkpatrick model has been widely used by organisations due to its effectiveness in systematically evaluating training outcomes (Bates, Citation2004). To assess the model’s effectiveness, Smidt, Balandin, Sigafoos, and Reed (Citation2009) explored six studies dedicated to outcomes of communication-based training that employed the Kirkpatrick model. The authors concluded that the Kirkpatrick model provides a useful technique for assessing a training programme and for evaluating whether it meets the needs of the participants and requirements of an organisation. In this regard, the Kirkpatrick model provides a useful guide to assess the learning outcomes of the present study. Prior to the present study, Kirkpatrick's model had not been employed to assess learning outcomes in apparel research and specifically with respect to teaching and learning 3D technologies. The results of the study, therefore, extend application of the model to studies on teaching and learning virtual apparel product development technologies.

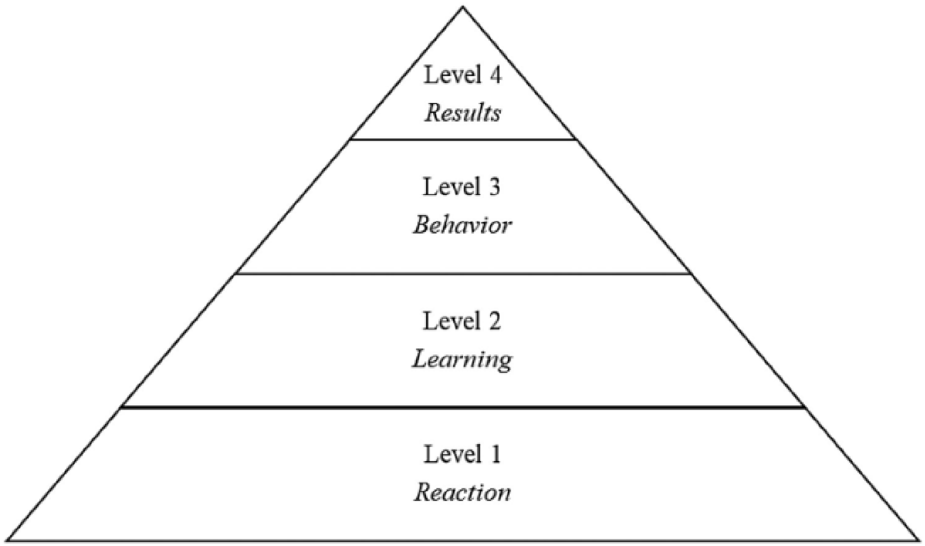

Figure 1. Four stage evaluation model by Kirkpatrick (Citation1994).

According to Kirkpatrick (Citation1994), the four levels take place in the context of the learning environment (e.g. a company) and occur in a stepwise manner. It is important to note that the Kirkpatrick model was designed as an objective measure of the effectiveness of training programmes. However, learning is also a highly subjective process, in that learners bring their own unique and individual experiences and expectations to the learning process which must be taken into consideration (Cullen, Harris, & Hill, Citation2012). This is particularly the case when it comes to learning a new technology, in that each individual brings different degrees of knowledge, skills, and aptitude to the process (Chang, Citation2014). In the present study, factors at the individual level and those that emerged through the four levels of the evaluation process were explored in order to fully understand the response to and outcomes of students' exposure to learning a new virtual prototyping technology. More specifically, the first two levels of Kirkpatrick's framework, Reaction and Learning, were assessed through a comparison of students' scores before and after learning the virtual prototyping technology. The latter two levels, Behaviour and Results, were assessed through qualitative data.

3D/virtual technologies

According to Power (Citation2013), 3D simulation has become so widespread in recent years that students who graduate with a degree in apparel design are now expected to understand aspects of 3D simulation, including spatial visualisation, virtual fit, and rapid prototyping. Because spatial visualisation involves the ability to imagine the relationship between space and objects, it is key to developing the skills needed to transform 2D patterns to 3D garments. The literature indicates that training can improve spatial visualisation abilities (Aneroid, Citation1989). For example, in Braukmann and Pedras (Citation1993) study, training on 3D computer programmes was found to significantly improve spatial visualisation skills among participants. Likewise, virtual fit helps students 'visualise pattern modifications instantly in full 3D' (Park et al., Citation2011, p. 508), which reduces product development time and saves costs associated with producing the garment multiple times. Last, rapid prototyping allows students to assemble a full-scale model using 3D computer-aided design (Flowers & Moniz, Citation2002). As Workman and Zhang (Citation1999) noted, the creation of ideas is integral to the apparel design process, and these ideas must be clearly communicated to bring them to fruition.

A type of 3D simulation, virtual visual merchandising in virtual store environments is an applied technology that is becoming more widespread. Virtual merchandising refers to merchandise that is displayed and visually communicated to consumers in online retail environments (Wu, Kim, & Koo, Citation2015). Wu et al. (Citation2015) conducted a study with 145 students who were enrolled in visual merchandising courses. Students were asked to form small teams (2–3 individuals per group) and co-design a virtual store as part of a course project competition. Over two consecutive semesters, a total of 67 stores were co-designed using Mockshop, a software designed to create virtual retail spaces, following specific parameters (i.e. 30 by 25 ft. space, pre-selected fixtures). Once completed, the stores were analysed and findings revealed the visual merchandising elements that are part of the virtual store environment, potential relationships between these elements, and how these elements could serve as a foundation for exploring methodological frameworks for future research and practice. The study suggests that students who are introduced to visual merchandising in virtual stores develop an understanding of the discrepancies between displayed and actual products (i.e. objects displayed on a 2D flat screen vs. in a 3D virtual space). This understanding is important, as 3D technology has 'revolutionised the accuracy and the user experience of visualisation' (Wu et al., Citation2015, p. 540).

To examine the impact of exposure to virtual prototypes on students' skills in the context of a computer-aided patternmaking course, Baytar (Citation2018) developed a sequence of three projects. Using virtual prototyping software, the students were asked to respond to a pre- and post-test designed to assess their problem-solving skills, imagination, interaction, and to evaluate the performance of the technology as well as their intentions to use the technology. Findings of the study indicated that students' skills increased between the projects, as did their perceptions of the software performance. Specifically, exposure to virtual prototyping was found to help improve their visualisation skills over the course of the three projects. Per the literature reviewed here, carefully designed learning opportunities using 3D software can be useful for developing spatial visualisation skills and relating 2D to 3D and vice versa (Park et al., Citation2011). More and more, such skills offer students hoping to work as apparel designers, patternmakers, product developers, and even merchandisers, greater benefits in terms of career readiness and professional preparation. The present study seeks to add to the growing body of empirical research on the topic.

Spatial visualisation

According to McGee (Citation1979), spatial visualisation means the capability to manipulate a 3D object mentally, including the ability to envision rotating the object, folding and unfolding the object, and picturing changes in position as the object moves from flat to three-dimensional. Spatial visualisation, therefore, requires understanding how an object appears, how it changes in three-dimensions, and the ability to imagine the object from different viewpoints in order to recreate it (Strong & Smith, Citation2001). It is further referred to as the ability to perceive an object horizontally, to rotate it mentally, and to perceive it embedded within a more complex figure (Linn & Petersen, Citation1985).

Such abilities have numerous important uses in fields like engineering, math, and physics (Rhoades, Citation1981). Likewise, it is well documented in the literature that spatial visualisation is not only important, but a necessary skill for success in architecture and mechanical engineering (Battista, Citation1994; Eisenberg & McGinty, Citation1977; Harris, Citation1981; Miller & Bertoline, Citation1991; Rhoades, Citation1981). Research also indicates the significance of such abilities for success in apparel design and product development (Morris et al., Citation2015; Park et al., Citation2011; Workman, Caldwell, & Kallal, Citation1999; Workman & Zhang, Citation1999). This is because the ability to visualise a garment and how it will fit and move on a body early in the design process is a vital step before construction begins (Park et al., Citation2011). Patternmakers utilise manipulative, analytic, and visualisation skills (Workman & Zhang, Citation1999) to understand how the two-dimensional pattern pieces will connect to create the three-dimensional shape of the finished garment, and how adjustments such as dart position or manipulation will impact the resulting silhouette. Moreover, spatial visualisation activities can often enhance creative thinking, not just by creating a 3D garment from a 2D design, but by working in reverse, to create flat pattern pieces based off of a 3D garment (Workman & Caldwell, Citation2007).

Spatial visualisation may be measured by assessing a number of different abilities. As Linn and Petersen's (Citation1985) meta-analysis indicated, three key categories of tests, including spatial perception, mental rotation, and spatial visualisation have typically been used to measure spatial visualisation abilities. Spatial perception establishes how well individuals can perceive spatial relationships with objects during the presence of distractions. It is often measured by orienting an object correctly with either gravitational or kinetic cues acting as distraction (Witkin, Dyk, & Faterson, Citation1962). Several varieties of mental rotation tests have been used to assess these abilities. In such tests, participants are usually asked to mentally rotate an object and are tested not only for accuracy, but also for speed (Cooper & Shepard, Citation1973; Shepard & Metzler, Citation1971; Vandenberg & Kuse, Citation1978). Spatial visualisation is associated with 'spatial ability tasks that involve complicated, multistep manipulations of spatially presented information' (Linn & Petersen, Citation1985, p. 1484). To this end, several tasks, such as Hidden Figures, Paper Folding, and Paper Form Board, have been designed to measure the spatial visualisation skills required to solve the tasks (Linn & Petersen, Citation1985).

In a similar study by Park et al. (Citation2011), three different teaching methods were evaluated in an introductory patternmaking course. Apparel design majors were observed as information was delivered through a traditional classroom lecture, 3D simulation instruments, and paper patternmaking exercises in a studio. Results from the study indicate that these teaching methods served to enhance a student's ability to visualise 2D patterns on a human body. Furthermore, 3D simulation instruments were found to have a positive impact on the learning curves of students in the course (Park et al., Citation2011).

Hypotheses development

To address the purpose of this study, four hypotheses were developed. The hypotheses assess students' attitudes toward and skills that are important to learning the virtual prototyping software. The literature indicates that students' acceptance of technology is strongly related to their internal beliefs and attitudes toward usage (Gu, Zhu, & Guo, Citation2013). Baytar's (Citation2018) study revealed that students' perceptions of a virtual prototyping software are important for their learning experience and could be improved after a sequence of exercises utilising the software. Therefore, learning opportunities using virtual software designed to address students' attitudes toward the virtual prototyping programme may be useful for increasing skill levels. This link between attitude and skill development addresses the link between the first two levels of Kirkpatrick's (Citation1994) framework: Reaction and Learning. Thus, based on the literature and the framework, the following hypotheses were proposed:

> **Hypothesis 1:** The mean score on students' attitudes toward virtual technology after receiving the training on the virtual prototyping technology will be higher as compared to before receiving the training on the virtual prototyping technology (Level 1: Reaction).

> **Hypothesis 2:** The mean score on students' skill development after receiving the training on the virtual prototyping technology will be higher as compared to before receiving the training on the virtual prototyping technology (Level 2: Learning).

As discussed earlier, the literature indicates that spatial visualisation skills can be enhanced via exercises that involve virtual pattern-making activities (Baytar, Citation2018; Park et al., Citation2011), because students are required to manipulate 2D pattern pieces in order to develop a 3D garment in a virtual setting. Prior research indicates the importance of spatial visualisation skills for success in apparel design and product development. Spatial visualisation skills are often assessed through a paper folding test, which requires participants imagine the folding and unfolding of pieces of paper (Linn & Petersen, Citation1985). In the test, a hole is punched through folded paper and participants are asked to identify the resulting pattern of holes when the paper is unfolded. In light of the previous literature, and to further test Kirkpatrick's second level (learning) the following hypothesis was proposed:

> **Hypothesis 3:** The mean score on students' paper folding tests after receiving the training on the virtual prototyping technology will be higher as compared to before receiving the training on the virtual prototyping technology (Level 2: Learning).

In addition to the paper folding test, Workman et al. (Citation1999) developed a test to measure spatial skills. The test was designed to consider spatial storage, spatial products, and spatial thought. Participants were given pictures of apparel pattern pieces and asked to match them to garment sketches, requiring them to envision how the constructed garment would look based on the flat pattern pieces (Workman et al., Citation1999). The test was used to determine whether training in spatial abilities, as a result of the coursework, which included pattern making, draping and fashion illustration, improved test scores. Results of the scores indicated overall improvement. Based on the Workman et al. study, a similar test was developed for the present study, but instead of using 2D examples, students were asked to use the virtual prototyping software to complete the tasks. As further testing of learning per Kirkpatrick's framework, the following hypothesis was proposed for this study:

> **Hypothesis 4:** The mean score on students' spatial visualisation skills after receiving the training on the virtual prototyping technology will be higher as

compared to before receiving the training on the virtual prototyping technology (Level 2: Learning).

Method

A three-phased, mixed-methods research design (Creswell & Plano-Clark, Citation2011) was used to address the purpose of the study. With Institutional Review Board approval, students in a freshman/sophomore level apparel studies course at a large university in the Southeastern US were asked to participate in the study. In Phase I, an on-site presentation of a virtual prototyping software that is increasingly being used by apparel companies (Arribas & Alfaro, Citation2018) was provided to the students in the course by representatives from an apparel corporation that served as the project partner. The corporation employs thousands of people worldwide to produce its apparel products and is headquartered in the same city as the university where the study was conducted.

Phase II consisted of two weeks of training, during which time students were taught to use the software. Because it is a lower-level course, and one that is required of both design and retail merchandising students, they had little to no prior experience with either 3D simulation software or 2D/3D garment prototyping. During the two weeks of training, instructors covered basic tools of the software and how to use them. In the first week, students learned to manipulate avatar sizes, draft kimono dress patterns, dress the patterns on an avatar, and check fit. In the second week, all tools available in the software were covered. Then students drafted a skirt for an avatar of their selection, dressed the skirt on the avatar, and applied fabrics to the skirt virtually.

As part of Phase II, students were asked to complete a pre-test and post-test survey. The pre-test survey was distributed one week before the industry collaborator's presentation and subsequent training using the virtual prototyping technology. A total of 42 items found in the apparel-specific and more general technology pedagogy literature were included in the survey to measure three distinct variables: (1) Attitude toward virtual technology, with seven items adapted from Park et al. (Citation2011) and Limayem and Cheung (Citation2008); (2) Skill development, with eight items adapted from Gu et al. (Citation2013) and Liaw, Huang, and Chen (Citation2007); and (3) Spatial visualisation assessment, with 27 items total consisting of 20 paper folding test items adapted from Ekstrom, French, Harman, and Dermen (Citation1976) and seven virtual prototyping items developed by the researchers. Responses for the Attitude and Skill development items used a 7-point Likert scale, ranging from Strongly Disagree (1) to Strongly Agree (7). The paper-folding test is a part of a series of cognitive tests developed by the Educational Testing Service (ETS) to assess spatial visualisation skills, including the ability to interpret two-dimensional representations of three-dimensional objects. Respondents were first asked to mentally fold a drawing of a piece of paper with one or more punched 'holes' such that the holes match up in the finished piece. Respondents were then asked to mentally unfold the paper and respond to items asking them to identify the final locations of the hole(s). This test has been applied in several apparel studies investigating spatial visualisation (Park et al., Citation2011; Workman et al., Citation1999). Finally, the researchers developed seven questions using the 3D simulation software wherein the respondents were asked to match a depiction of a pattern piece with a depiction of a completed garment.

After the two-week training period, students were asked to complete a post-test which included the same items as the pre-test. Seven open-ended questions, designed to facilitate reflection on the learning process and assess its effectiveness, were also included on the post-test.

Examples of questions include: What did you like most about the experience? Why? What was the most challenging part of the experience? Why? and What did you learn that will help you function as a professional in the apparel industry? Students did not receive an incentive to complete the pre- or post-test surveys.

Phase III was comprised of in-depth interviews in which students were asked to reflect more broadly on the learning experience. Questions included, How might learning a new technology benefit you? Why? and What do you think is important about learning a virtual technology? A total of 15 students participated in the audio-recorded interviews. Interviews lasted from 30 to 60 minutes, and each participant received a small incentive in the form of a $5 retail gift card. Interviews and responses to open-ended post-test questions were transcribed verbatim for analysis and interpretation.

As discussed earlier, Kirkpatrick's (Citation1994) four-level model for evaluating workplace training was augmented by concepts important to learner-centered pedagogical practice (Cullen et al., Citation2012) to form the conceptual framework for interpretation of the data. Reaction and Learning, two of the levels outlined by Kirkpatrick (Citation1994), were assessed through a comparison of students' scores on the pre- and post-tests (H1-H4). However, because a student's unique experiences and expectations will often drive the learning process (Cullen et al., Citation2012), the other two levels, consisting of Behaviour and Results, were evaluated through the qualitative data.

Results

A total of 40 complete and matched pre- and post-tests were analysed. Participants were largely between 18 and 20 years of age (85.0%) and female (90.0%). Most participants identified themselves as African American (42.5%) or Caucasian (35.0%). The majority of participants (65%) identified themselves as being freshmen (47.5%) or sophomores (17.5%).

Repeated measures experiment

To determine whether the training period had an effect on students' attitudes and skill development, a repeated measures experiment design was used, wherein each participant completed the survey two times, once before the software was introduced and again after training on the software was complete. Table 1 shows the means and standard deviations of students' attitudes toward virtual technology, skill development, and spatial visualisation skills in the pre- and post-tests and the results of the paired sample t-tests. In addition, Table 1 includes reliabilities of each measure.

The paired sample t-test results indicate that the means of attitudes toward virtual technology ($M_{Pre\text{-}test} = 5.60$ vs. $M_{Post\text{-}test} = 5.89$, $M_{Diff} = 0.30$, $t = 2.713$; $p = .010$) and skill development ($M_{Pre\text{-}test} = 5.32$ vs. $M_{Post\text{-}test} = 5.71$, $M_{Diff} = 0.39$, $t = 3.339$; $p = .002$) increased significantly in the post-test when compared with the pre-test, supporting H1 and H2. In addition, the mean score of paper folding test and spatial visualisation skills also increased significantly in the post-test as compared with the pre-test (Paper folding test: $M_{Pre\text{-}test} = 9.65$ vs. $M_{Post\text{-}test} = 11.55$, $M_{Diff} = 1.90$, $t = 4.395$, $p < .001$; Spatial visualisation skills: $M_{Pre\text{-}test} = 3.95$ vs. $M_{Post\text{-}test} = 4.75$, $M_{Diff} = 0.80$, $t = 3.361$; $p = .002$; respectively), indicating that participants'

Table 1. Pre- and post-tests of attitudes, skill development, paper folding, and spatial visualisation skills and results of paired sample t-test (n = 40).

	Pre-test		**Post-test**		**Paired sample *t*-test**		
	Mean (SD)	**Alpha (α)**	**Mean (SD)**	**Alpha (α)**	**Mean diff**	***t* value**	***p*-value**
Attitudes toward virtual technology	5.60 (0.87)	0.75	5.89 (0.83)	0.87	0.30	2.713	0.01*
Skill development	5.32 (1.02)	0.94	5.71 (1.04)	0.93	0.39	3.339	0.002**
Paper folding test (20 questions/score range from 0 to 20)	9.65 (4.25)	0.84	11.55 (3.91)	0.87	1.90	4.395	<.001***
Spatial visualisation skills (7 questions/score range from 0 to 7)	3.95 (1.72)	0.83	4.75 (1.45)	0.81	0.80	3.361	0.002**

Note: *$p < .05$, **$p < .01$, ***$p < .001$; SD = Standard deviation.

Thematic interpretation of qualitative responses

To investigate students' experiences in terms of behaviour (level 3) and potential for meaningful results (level 4; Kirkpatrick, Citation1994), the open-ended questions and interviews were transcribed and thematically interpreted by two members of the research team. Analysis was completed first by organising responses to the open-ended questions and the interview questions into coded categories of meaning. Categories were then iteratively compared for similarities and differences and merged in cases of overlap (Keegan, Citation2009). From there, three primary emergent themes were identified which elucidate students' perceptions of the software in terms of: (1) achieving personal learning goals, (2) understanding professional expectations, and (3) relating to future career goals. To maintain anonymity, respondent names were changed to numeric identifiers. Responses are labelled as either DI (depth interview) or PST (post-test) to indicate response context.

Achieving personal learning goals. Students were asked to respond regarding what they experienced with the training process and how they felt about it. One of the foremost issues to emerge was the extent to which learning the software helped them feel like they accomplished something. For example, one student expressed during the interview that she 'loved getting to learn about this technology and being able to practice with it' (PST6722). DI7 pointed to the long-range benefits of learning and using the latest in technology, stating that:

> It saves time and it keeps you ahead of the curve. So, you learn how to do something that will make you more productive and more productive on down the line. So, you can do a job a lot faster. Saves you money, saves you time and it starts helping you get established out there faster. So, at some point, you can start climbing up the ladder and get yourself to the status of what you want to be.

Other responses pointed to the more specific task-related learning that can be augmented by the technology. For example, one student wrote, 'I've always been fascinated by stitching and sewing and I liked that this was a different approach to it' (PST8821). Another student wrote that 'It helped me understand how one wrong adjustment can mean a bad fit and I liked that because it made me pay attention more to what I was doing' (PST3562). One student expressed the practical value of working virtually for learning more about the relationship between fabric and garment, stating, 'I get to learn how the fabric is shown on a model rather than trying to guess how it would appear on them' (PST8973). Similarly, another student commented on the value of being exposed to the link between a flat pattern and a body form, writing 'I like that I can see how a 2D pattern could fit into a 3D form. I haven't seen this before' (PST6722). Such responses indicate the importance of reflecting on the learning opportunity to better understand the subjective nature of the process for the individual learner (Cullen et al., Citation2012).

Reflections also included some of the more challenging aspects of the experience. Learning a new software, especially one that does not resemble other technologies that the students have used before, led to some difficulties and even frustrations. Multiple responses indicated the need for more time to explore the software's tools and to better understand its capabilities, including one student, who wrote 'The amount of time we got to spend using it should definitely increase. Just when it started becoming familiar and cool we were done' (PST4274). However, many of the responses also indicated an understanding of the extent to which learning something new generally involves difficulty, as one student wrote, 'It was hard to figure out, lots of tools and options to use, but that is normal with any new software' (PST6887). One response reflected the crux of the challenge being addressed by the study itself: the ability to move from two dimensions to three dimensions and back again. She explained,

> Um … taking stuff either from virtual to the real world or like the real world to virtual. Because it's not easy at all. It's very difficult so that is probably honestly what I have the hardest time with. (DI5)

The reality of the dynamic nature of technology in general also surfaced among the responses. That is, today the virtual prototyping software may be new, but tomorrow there will be something else to learn and apply. DI4 pointed to how this understanding is an important part of the learning process, stating: 'I think to understand it is constantly changing. Once you get comfortable with [using] one thing, it changes [and] you need to learn something else'. Likewise, most software is updated on a regular basis, such that a single programme can change frequently, requiring users to learn new capabilities and tools even if they are proficient in using the general programme.

Obviously, the students participating in this study are of a generation that has grown up with technology and are aware of its hallmark of constant change, therefore, it is not surprising that at least a few of the comments would reflect this sensibility. However, one student's response indicates a broader understanding of why it is important, from a personal standpoint, to be able to learn and adopt new things, stating,

> I think it's important just to be familiar with new concepts, new software. Um, I think a lot of jobs now are creating new things that, you know, maybe the older generation aren't so used to. So, I think it's just good to be caught up with what's up to date and just being aware of how to use simple things, because you never know … you never know what you have to use for a job. Um, so I think it's just helpful. Just being caught up on the latest trends of, you know, technology, because everyday, like I said, it's changing. (DI7)

Comments like this one suggest that students were able to move through the first two levels of Reaction and Learning and into the third (Behaviour), in the sense that they saw the value of the learning opportunity not just in terms of becoming practiced with a particular software, but realising that they are capable of learning to apply something they had never used before – a capability that has application well beyond the virtual prototyping software addressed by this project. As one student put it, the experience 'proved that I was able to easily adapt to a new program' (DI2).

Understanding professional expectations. In Phase I of the project, individuals representing the industry collaborator visited the class to present the software and talk about its uses and benefits for the company as well as the apparel industry as a whole. Thus, the learning opportunity was framed by information about why it is important to know how to use virtual prototyping to work in the industry. Although the faculty member teaching the course could have given a similar introductory presentation, the point was to involve industry 'experts' in the process of exposing students to the technology for the first time. This approach seemed to be effective, as some students extrapolated the more general message provided by the industry speakers to their own professional development. One student wrote that the most interesting aspect of the project was, 'Learning a technique that employers look for. Being able to work [this software] will hopefully help when I graduate and look for a job' (PST0135). Another seemed to realise the value of the industry collaborator's presence as part of the process, 'I was able to learn a little about how professionals work' (DI11). Having individuals from the 'real world' of work talk about the importance of virtual technology seemed to resonate with many of the students, pointing to the importance of the individual learner's point of view in the process of developing projects and curriculum for teaching virtual technologies.

Another participant talked about why framing the learning process as one based in real-world knowledge was important to motivating her to learn the software, so important that it was the most interesting aspect of the project for her:

> I think the most interesting part [was] hearing how it is supposed to help me. We've learned a lot of different software technology. Sometimes it seems like it doesn't necessarily make the process easier. So, I like seeing how that eliminates an issue with the design process itself. So just knowing how it's supposed to make my job easier is beneficial for me, not just knowing that I can do better, but that I understand the purpose of learning [the technology] in general. (DI3)

The idea that there is a purpose to learning the new software and that the process will be worth it in the long run suggests an understanding of the value of learning from a practical perspective. Indeed, one student responded similarly, but a little more bluntly, on this point, stating:

> Maybe if you don't learn it, you're going to not have a job. Oh yeah. That's the main thing. If you don't learn it, technology … you can't be paid for showing up and … doing nothing. You can't have a job [if] you can't actually perform the task. (DI14)

Relating to future career goals. Although the students may be focused on what learning the virtual prototyping programme can do for them in terms of achieving personal goals or understanding job-specific expectations, there were many who also addressed the big picture of what being technologically proficient means for their overall careers. Because the class included students in both design and retail aspects of the major, the project was developed to address the role of prototyping relative to both primary industry functions. That is, this project did not focus just on how the software can be used for patternmaking. Instead, it focused on how decisions that are made in 2D impact the resulting form in three dimensions, which is information that is vital to anyone working with apparel products. Several students seemed to grasp this idea, as reflected in responses from those interested in design, 'I like learning how this technology can make a fashion designer's job easier and more realistic. I will seek to use this in the future' (PST0188), as well as those in retail, 'As a future buyer, this will help me create models to show the company, that way my ideas can be seen as creative' (PST4510).

Perhaps the most telling understanding of how effective the learning opportunity was for non-design students came through in this forward-thinking response from a retail student: 'Hopefully, I will be able to better understand limitations designers face when I am buying from them' (PST1631). Oftentimes in apparel programmes, retail/merchandising students do not get a lot of exposure to what goes into the making of an apparel product. Being able to see virtually how small changes in pocket design and placement, stitching, closures, and other elements of garment construction can result in rather large changes to the garment (and in turn, increases in cost) before anything is actually produced is very valuable knowledge for merchandisers who may not have years of industry experience to draw upon. Such knowledge could ultimately have a positive impact on a student's career trajectory, even if that student is not interested in working as a designer per se.

The goal of the project was to introduce students to the possibilities of working virtually with apparel products. By including an industry collaborator in the process, the hope was that the students would see the big picture of the technology not just for their degree programmes, but also for the careers they will ultimately forge, thereby achieving Kirkpatrick's fourth level: Results. In terms of this project, Results means that learners have gone beyond the ability to understand and apply the skills that they have learned (levels 1–3), to the point where they can envision a positive future return on the investment they put into the learning opportunity, not just for themselves, but for their place within the larger industry. One student put it succinctly when he said that the ultimate test of the value of the learning experience for him was,

> … when you start thinking about your future and what jobs are in the industry. Of course, you are going to be, you want to have as many options as possible so you can make the best decision for your lifestyle. The only way you can do that is if you know more, cause this, this field of apparel is really saturated. So, there are a lot of people in the industry competing for the same spot you are. The more you know about different technologies, even if it's a little bit, you'll still probably be more likely to go further than somebody who doesn't know certain aspects of technology. So that's the most beneficial part. (ID5)

Conclusions and implications for teaching and learning

Results of this study revealed both benefits and challenges of learning virtual technology. Challenges included the time required to fully understand its capabilities. Indeed, one of the most frequent responses to the question of what students liked least was that there was not enough time to fully explore the virtual prototyping software. Although the presentation of the material by the industry partner was important, it appeared to be more important to practice using the technology, that is, to engage in behaviours that will develop further skill in the use of the technology. However, understanding the potential for applying the learning more broadly did emerge as a meaningful result of the overall learning experience. That is, the students seemed to appreciate the collaborative approach and presence of the industry partner, to the extent that the context this provided allowed them to better understand how gaining experience with virtual technology applies to their future careers.

The mixed methods approach used in this study enhances the literature on the topic as it provides a broad, yet in-depth examination of the experience of learning a virtual technology. For example, based on the results of the pre- and post-test repeated measures analysis, exposure to the virtual prototyping software appears to have had a positive impact on students' spatial visualisation skills, as well as developing more positive attitudes toward the technology. Based on the interpretation of the qualitative data, it appears that the more that students are provided the opportunity to learn to use virtual technologies, the more they believe that they will be able to complete work-related tasks, including those that involve learning new work-related technologies. Employing a mixed-methods approach allowed for measuring degrees of skill development alongside building an in-depth understanding of the learning experience.

Although researchers have sought to explore how technologies can help students develop stronger skills related to design (Baytar, Citation2018; Park et al., Citation2011; Workman et al., Citation1999; Workman & Zhang, Citation1999) and merchandising (Wu et al., Citation2015) separately, this study is among the first to include both design and retail merchandising students in a single virtual technology learning opportunity. This approach mirrors the apparel industry workplace, in that much of the work is team-based and crosses over and between areas, as does the use of virtual technologies (Arribas & Alfaro, Citation2018). Indeed, virtual prototyping is not just important for designers and product developers. Merchandisers and buyers also benefit from being competent in using the technology, as it provides a basis for in-depth product knowledge without the skills required to create designs or to put actual garments together. Other benefits of adopting virtual prototyping technology across the apparel product development cycle include reductions in cost and material waste, along with more efficient and effective communication between work groups (Arribas & Alfaro, Citation2018).

The application of the Kirkpatrick framework contributes to the literature in multiple areas. To our knowledge, this framework has not yet been applied in research on three-dimensional learning and skill development. The first two levels outlined by Kirkpatrick, Reaction and Learning, were assessed through a comparison of students' scores on the pre- and post-tests. The other two levels, consisting of Behaviour and Results, were evaluated through the qualitative data and framed by the understanding that students' experiences and expectations are important to their motivations during the learning process (Cullen et al., Citation2012). In the case of the students in this study, their motivations were related to their own professional and career goals. Thus, results of this study offer insight into how the framework may be used to assess learning in ways that are germane to the apparel industry. Likewise, the presence of the industry collaborator to introduce the software and demonstrate its uses and capabilities ahead of time framed the virtual technology as something that is 'now' and will become even more important in the future. This approach seemed to prompt the students to be more open to the idea of learning it, and this openness may have, in turn, helped them better understand why learning it is essential. An important next step would be to integrate the industry collaborator through the second phase, including more interaction between students and industry professionals in the development and evaluation of skills and abilities using the software. Likewise, testing the process with juniors and seniors, as well as across cohorts as part of a longitudinal research design, would shed greater light on the extent to which knowing how to use the technology helps students achieve personal and professional learning goals. Such approaches would also help to address changes in technology learning goals over time and as students become more knowledgeable of the curricular subject matter as a whole.

Although findings of this study contribute to what is known about how students learn, and specifically how they learn a virtual technology application, further development and testing of pedagogical approaches are needed. Studies that employ larger samples and more diverse methodologies would be particularly useful. Although the comparison of pre- and post-test means revealed a positive difference across the three variables, it is difficult to establish that exposure to the technology was the only reason for this difference. The qualitative data help to fill in some of the gaps, but the small sample size makes it difficult to generalise based on findings.

Incorporating virtual technologies into the classroom, and especially those that are important to the future of the apparel industry, is a necessity because it ensures currency and relevancy of the curriculum. At the same time, it addresses students' professional development needs. While there is still much to be discovered about how apparel students learn to use virtual technology, the results of this study add to the growing body of empirical research on the topic and contribute to developing best pedagogical practices.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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