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Interactive Infographics Improve Learning Outcomes in a Food Science Laboratory Exercise Environment

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Abstract

Laboratory exercises are a crucial component for many science education courses. Hands-on activities provide valuable contextualized learning experiences and allow for increased engagement between students and technical knowledge. The present study examined the efficacy of a virtual-type laboratory activity compared to a traditional hands-on activity. Food science undergraduates (*N=35*) were randomly assigned to two groups: (1) performing a virtual lab exercise and (2) performing a traditional hands-on exercise producing mozzarella cheese. The virtual lab exercise consisted of interactive infographics highlighting the chemistry of the mozzarella making process, incorporating clickable animation, audio voiceovers, and minimal narrative text. The virtual lab group demonstrated a significantly larger increase in cheesemaking knowledge (p<0.0001; d=*1.49*) than the traditional lab group (p=0.41; d=0.26). Both groups exhibited significant increases in cheesemaking self-efficacy. These data suggest that interactive infographics can function as effective learning tools in technical education.

Keywords: infographics; virtual laboratory; science education; food science education

Introduction

Educating the next generation of the scientific workforce has been the focus of much research attention in recent decades. Specifically, undergraduate and graduate programs have been developed focusing on the intersection of food technology, agriculture, and STEM literacy (Chakraborty et al., 2017). The pressing need to address the skills gap in these students entering the workforce has been driven by the growing global population, poverty-induced hunger, and nutritional challenges such as obesity and heart disease. Systems-type approaches are actively being developed and implemented to educate the future workforce to ultimately combat these issues (Ingram et al., 2020). At the same time, food and agriculture industry stakeholders have expressed a need for workforce development programs in order to develop the talent pool for the next generation of employees. The growth in food/agriculture-related jobs has resulted in a dynamic labor market that requires students with background training in the technical aspects of food/agriculture production, preparation, and safety (Tomich et al., 2019).

As the workforce grows so does the necessity for workplace training and technical education. The specific aspects of the instruction needed varies depending on

the specific food industry sub-sector (e.g., dairy products, baked goods, etc.). However, many skills are broadly applicable and crucial for food workers to acquire. Topics such as food safety/sanitation, food sustainability, and food processing phenomena are key areas that are essential to ensuring ongoing nutritional security and safety of our food supply. Moreover, the economic repercussions of not properly addressing these subjects can be substantial. Annual estimates range from $30 billion to $140 billion for the burden of foodborne illnesses on health-related costs and losses in productivity (Scharff, 2012). These economic losses, and more importantly losses of life and well-being, can be at-least partially remedied with a more robust food system composed of a well-trained workforce with access to the highest quality technical education available.

Limitations of Traditional Laboratory-type Exercises

An important component of technical education and training are hands-on laboratory-type exercises that expose learners to "real-world" or "practical" situations faced in the food-manufacturing sector. Lab exercises also serve as instructional tools that instructors can use to engage students and establish active learning environments in the sciences (Lamichhane & Maltese, 2019). However, traditional lab exercises often require dedicated facilities, costly materials, and small class sizes in order to be effectively completed. These intrinsic hurdles to lab instruction are becoming greater with the rise of social distancing guidelines and limitations placed upon higher education institutions due to COVID-19 related practices. Indeed, traditional laboratory exercises will have to evolve to provide meaningful and engaging instruction with the "new normal" many institutions now face.

The advent of remote learning and e-learning environments can help address these challenges (Brandt et al., 2010; Carruth & Carruth, 2013). However, a range of issues often hinders the efficacy of these technologies and overall learner engagement in these scenarios. Technology literacy, cultural barriers such as language, and non-engaging learning material are often cited as barriers (Becker et al., 2012). One possible method to address these challenges and meet the needs of these learners is the development of visually engaging educational materials via electronic instruction. In traditional educational settings, visual aesthetics is often an ancillary consideration (Miller, 2011). The growth in the use of private-sector online platforms/ecosystems, such as social media, banking, and news media, have raised the expectations of consumers vis-à-vis visual engagement (Sánchez-Franco et al., 2014). Concomitantly, the line between physical and virtual media has become blurred in many ways as traditional "paper" media types are now being viewed on computer and smart phone screens (e.g., magazines, white papers).

Infographics in Educational and Communication

When considering the next frontier of multimedia material for engagement and instruction, a specific example of interest are infographics. Infographics—a portmanteau of "informational graphics"—combine text and visual elements in aesthetically-pleasing combinations with the goal of informing and teaching (Naparin & Saad, 2017). These tools can be viewed statically on paper (handout) or on a screen (pdf), and can also be interactive (simple point-and-click animations). This level of interaction, combined with pleasing visual aesthetics, can create powerful learning

tools. Both interaction and pleasing visuals have been shown to decrease cognitive load while simultaneously increasing learner satisfaction and engagement (Agarwal & Karahanna, 2000; Lavie & Tractinsky, 2004; Miller, 2011).

Infographics have been used to effectively communicated and education on complex subject such as organic chemistry (Kothari et al., 2019), mathematics (Sudakov et al., 2016), health public policy (Otten et al., 2015), and food technology (Schmidt, 2009). However, a dearth of knowledge exists utilizing infographics combined with interaction in the context of laboratory exercise-type activities. Much of the work to date has been focused on popular culture subjects for academic audiences (e.g., undergraduates learning about food labelling), and does not address specific food technology topics such as manufacturing processes and food molecular chemistry. Moreover, the sparse literature relating to food/agriculture infographics centers on general-knowledge topics and not necessarily on specific, technical education content (Burnett et al., 2019). It is reasonable to assume that the benefits of infographic learning would facilitate learning in a food molecular chemistry lab.

Application to This Study

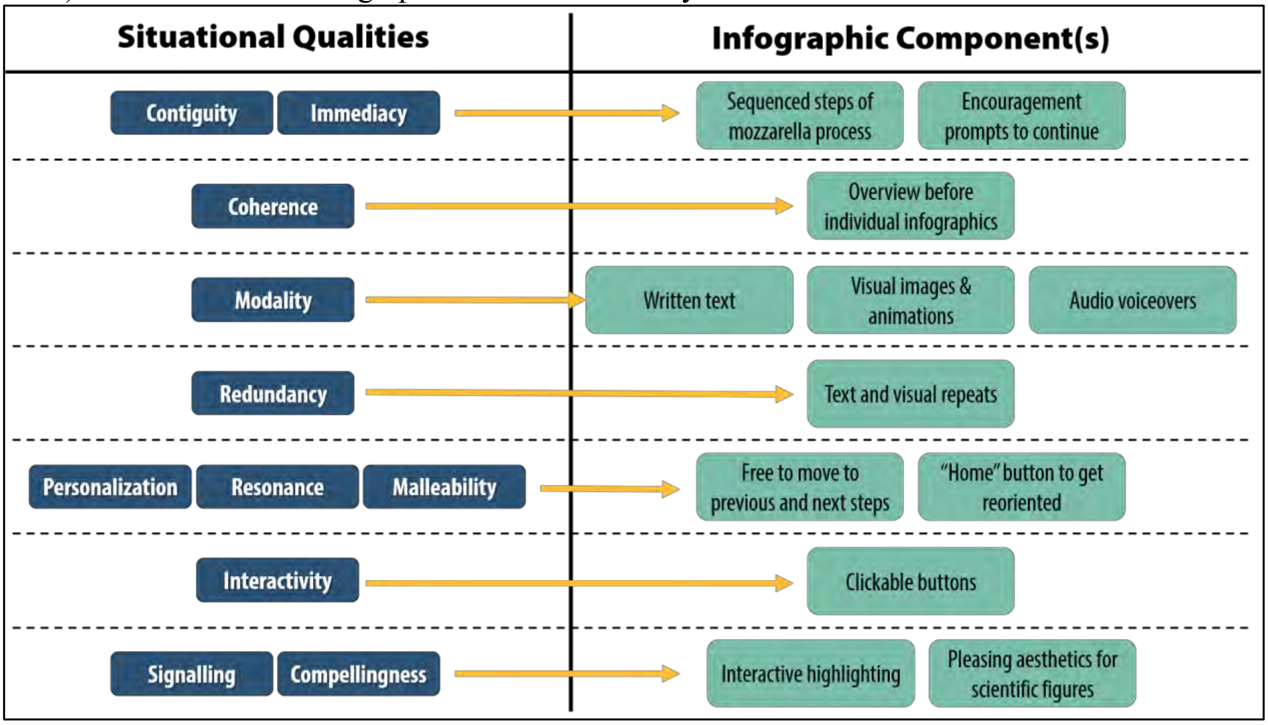
Given the need to further develop transformative learning activities for food technology workforce training and development, an opportunity exists to create a suite of visually engaging learning materials designed to address the workforce development challenges in the food and agriculture realm. For the current study we developed a series of interactive infographics outlining the steps of mozzarella cheese manufacturing and the underlying food chemistry theories responsible for the cheese's properties. This topic area was chosen for the following reasons: (1) mozzarella cheese production has distinct steps which can be effectively partitioned into separate infographic "vignettes", (2) each step of the process has numerous associated chemical and physical phenomena, and (3) the scientific principles demonstrated in this activity are widely transferable to other areas of food technology (e.g., thermal treatment, protein interactions, etc.). Thus the purpose of this study is to investigate the effect of interactive infographics on food science knowledge gain and overall self-efficacy on undergraduate students.

Theoretical Frameworks

Two theoretical frameworks were used in this study relating to visual aesthetics and multimedia learning for the creation of the interactive infographics. The Aesthetic Learning Experience Framework presents general principles that can be utilized to create compelling aesthetic learning experiences in a wide variety of contexts and media (Dunlap & Lowenthal, 2011; Parrish, 2007). Moreover, well-designed aesthetic learning experiences allow for learners to engage in transformative and memorable instruction, similar to that of traditional laboratory exercises. Dunlap & Lowenthal (2016) built upon the aesthetic learning experience framework and identified several core principles that create effective infographics vis-à-vis visual aesthetics. These principles are referred to as "situational qualities", in which learners should experience while viewing infographics: immediacy, malleability, compellingness, resonance, and coherence. Mayer (2002) proposed a similar framework which highlights principles of multimedia learning—multimedia, contiguity, coherence, modality, redundancy, personalization, interactivity, and signalling—that influenced the construction of the infographic

learning tool. Figure 1 outlines how the theoretical frameworks, and their foundational principles, were applied to the interactive learning tool created and used in this study.

Figure 1. Application of the Aesthetic Learning Experience Framework (Dunlap & Lowenthal, 2016; Parrish, 2007) and Cognitive Theory of Multimedia Learning (Mayer, 2002) in the interactive infographics used in this study.



The infographics created for this study build upon traditional infographic-type media by incorporating visual and audio modalities and interactive approaches. They were computer-based, with clickable regions, displayed motion-based animations, and included audio voiceovers. Importantly, the infographics provided aesthetically pleasing demonstrations of complex molecular processes required to understand the mozzarella making process. The infographics also allowed students to revisit the processes if any lack of coherence is detected during the learning process (i.e. metacognitive monitoring; Deroy, Spence, & Noppeney, 2016). Furthermore, the interactivity and use of multiple graphical and text elements on each infographic created a free-choice-type learning environment.

The situational qualities afforded in multimedia learning should result in a more durable memory of the to-be-learned information than information presented in a single modality (Clark & Paivio, 1991). Information presented in an in interactive manner also affords the opportunity for students to engage with the content and generate new knowledge, rather than passively acquiring the information through lectures or reading a handout (Chi & Wylie, 2014). Importantly, students were also given visualizations of the chemical changes that occur in each step of the mozzarella making process that would not otherwise be seen by the naked eye. Although traditional lab instruction requires students to engage in 'hands-on' activities, the physical task of completing the laboratory may interfere and override the importance of comprehending the causal steps and changes in chemistry at the molecular level. For these reasons, it was predicted that the interactive infographic learning would facilitate students' understanding of

mozzarella making, relative to traditional, hands-on instruction in a university lab course environment.

Methods

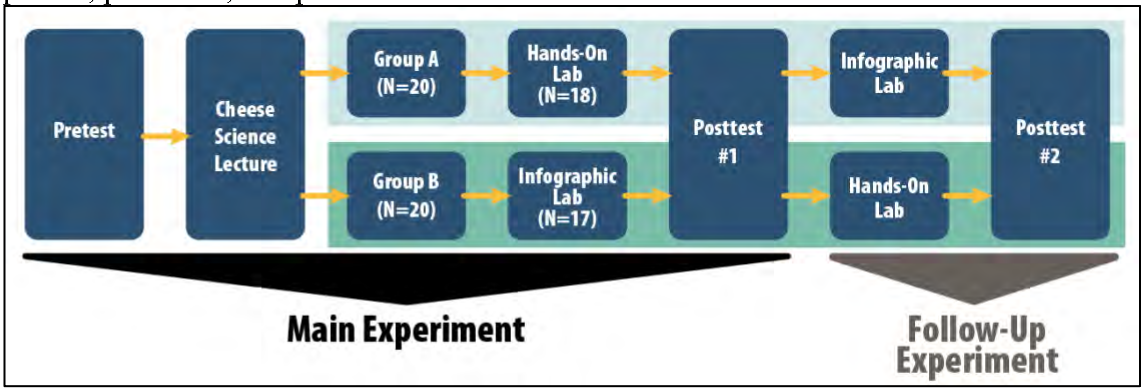
Participants

Participants were students enrolled in the "Introduction to Fermentation Sciences" course within the Food Science department at a large Midwestern research university. Forty students enrolled in the course and 35 students successfully completed all aspects of the study. Participant's average age was 20.5 (*SD*=2.2). Fifty-four percent were female. The majority of participants were White (63%), while 6% identified as African-American, 14% identified as Asian, 9% identified as Latino, and 9% identified as multiracial. Sixty percent had an academic major of agriculture, 3% were business, 11% were engineering, 23% were science, and 3% were technology majors. A majority of the participants were pursuing agriculture or science majors (83%) and had not previously made mozzarella cheese (89%).

Experimental Design

The study was designed as a two-phase experiment following a pretest-posttest design. An overview of the experimental design is presented as Figure 2. The main experiment consisted of all study participants first completing a pretest to gauge basal level cheesemaking knowledge, cheesemaking self-efficacy, and attitudes relating to different type of learning activities. Questions relating to demographic information was also included in the pretest.

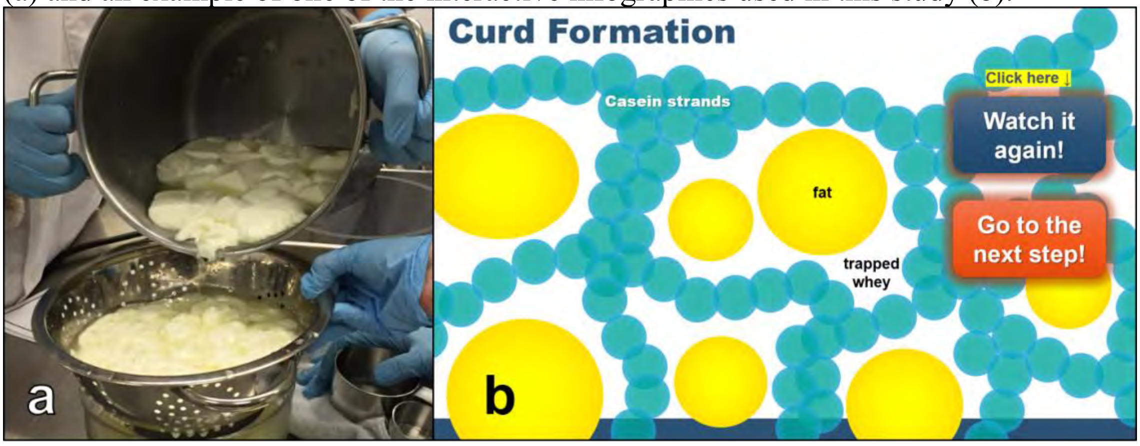
Figure 2. Experimental design used in the study. Participants were matched for the pretest, posttest 1, and posttest 2 assessments.



After completion of the pretest, all participants were then lectured on cheese science fundamentals covering basics of dairy technology and cheesemaking principles. The cohort was then divided into two groups, with participants randomly assigned to a "Hands-On Group" (Group A) or "Infographic Group" (Group B). The Hands-On group completed a traditional laboratory exercise in which they made mozzarella cheese (Figure 3). The laboratory handout they received detailed each step of the mozzarella production procedure and highlighted the underlying physicochemical theories involved with each step (Supplementary Information 5). There were no visual aesthetic elements presented to the Hands-On Group during the laboratory exercise. This served as the control group. The Infographic Group completed a virtual-type laboratory procedure

using a series of infographics. Each step of the mozzarella making procedure was displayed on their personal computers with interactive elements that combined text and visuals (Supplementary Information 6). The participants were free to "replay" each step or go back/forward between steps. The participants completed the virtual lab in a classroom separate from the traditional laboratory space After both groups had completed their respective learning exercises, a posttest was administered. The posttest was identical to the pretest except for the addition of the participants' impressions of the laboratory exercise and the demographic questions.

Figure 3. Study participants making mozzarella cheese in traditional laboratory setting (a) and an example of one of the interactive infographics used in this study (b).



Following this main experiment phase, a follow-up experiment was performed. The Hands-On Group, who had already completed the traditional laboratory exercise, then completed the interactive infographic exercise. Conversely, the Infographic Group then completed the traditional mozzarella making laboratory exercise. This approach was implemented for two reasons: (1) to determine if any knowledge gaps could be addressed by completion of both laboratory exercise types, and (2) to recognize differences in attitudes/impressions of the participants having been exposed to dramatically different learning exercise types. A final posttest was given to collect information relating to these two goals.

Instruments

Several instruments were used to capture participants cheesemaking knowledge, self-efficacy in cheesemaking/cheese technology, and attitudes/impressions of the different learning modality types (i.e., Hands-On vs. Infographic). Each of the instruments are available in Appendix A.

Cheesemaking Knowledge Evaluation

A ten-question test was developed to evaluate the participants' knowledge of the basic steps of the cheesemaking process and the underlying food chemistry mechanisms critical to the cheesemaking process. The test consisted of six multiple choice/multiple answer questions and four true/false questions. Questions were developed in consultation with several cheese technology professionals and cheese manufacturing experts with advanced subject matter knowledge. The questions were designed to

measure participants' knowledge of the cheesemaking process and the underlying chemical phenomena. This instrument was administered during the pretest, posttest 1, and posttest 2 phases of the study. Questions were kept identical throughout each of the testing phases.

Cheesemaking Self Efficacy Evaluation

A five-question evaluation was created to gauge participants' self-efficacy with regards to understanding the cheesemaking process and the basic dairy chemistry fundamentals associated with making mozzarella. This evaluation was adapted from the "College Biology Self-Efficacy Instrument for Nonmajors" (Baldwin et al., 1999). The questions utilized 8-pt Likert-type scales. Responses to these questions were collapsed into a single Cheese Knowledge Self Efficacy score.

Learning Modality Attitudes and Laboratory Impressions

A seven-question evaluation was adapted from Ambusaidi et al. (2018) to capture participant attitudes and impressions of: hands-on learning exercises, "virtual/electronic" learning exercises, and overall impression/efficacy of the specific laboratory exercise they completed. The questions utilized 8-pt Likert-type scales. Two of the seven questions were general questions relating to hands-on and electronic exercises. These questions were asked on all three evaluations (pretest, posttest 1, and posstest 2) along with the cheese self-efficacy questions (Table 2): "*I find hands-on exercises more beneficial to learning technical material than lectures*" and "*I find e-learning/point-and-click exercises useful to learning a topic*". The remaining five questions were asked only on the posttest 1 and posttest 2 evaluations due to relating directly to the laboratory exercises the study groups completed directly before the evaluation (Table 3).

Table 3. Participants' learning modality opinion after completion of both experimental phases (8-pt Likert-type Scales; 1 = Strongly Disagree, 8 = Strongly Agree).

Evaluation	**Posttest 1**	**Posttest 2**	**Post1/Post2 Diff**	
	Mean ± SD		P	d
I found this laboratory exercise easy to understand				
Hands-On Group	7.4 ± 0.7	7.4 ± 0.9	1.000	0.00
Infographic Group	7.1 ± 0.9	7.4 ± 1.0	0.5015	0.31
I found this laboratory exercise easy to complete				
Hands-On Group	7.5 ± 0.6	7.6 ± 0.5	0.7684	0.18
Infographic Group	7.5 ± 0.7	7.5 ± 0.7	1	0.00
I found this laboratory exercise stimulating				
Hands-On Group	7.4 ± 0.6	7.6 ± 0.4	0.2374	0.39
Infographic Group	5.9 ± 2.1	7.4 ± 1.0	0.0109	0.91
This laboratory exercise increased my knowledge of mozzarella making				
Hands-On Group	7.5 ± 0.6	7.6 ± 0.4	0.5516	0.20
Infographic Group	7.1 ± 0.9	7.7 ± 0.5	0.0435	0.82
I think this laboratory exercise would be easy/convenient to perform on my own				
Hands-On Group	7.2 ± 1.0	7.3 ± 0.6	0.7005	0.12
Infographic Group	6.7 ± 1.4	7.4 ± 0.7	0.0807	0.63

A validated instrument was also used to capture information related to participants' interest and impression of the lab types used in this study. An abbreviated STEM Semantic Survey (Tyler-Wood et al., 2010), which is comprised of five items

measured on a 7-point scale, was presented to study participants during posttest 2 evaluation phase. The instruments developed for this study all had acceptable internal consistency measures ($\alpha \geq 0.73$) as shown in Appendix A.

Interactive Infographics - Cheese Technology Lab

The "Infographic" laboratory exercise consisted of a series of interactive infographics built in Microsoft PowerPoint (Figure 3). Each cheesemaking step was broken down into its own vignette and presented via pictures, animations, etc. For example, the coagulation step included a button for students to add rennet. Upon rennet addition, a series of animations were shown demonstrating how the structure of milk changed into curd (casein micelle aggregation). Minimal text was used on each slide, and a voiceover was used which provided the same information as provided in the hands-on lab exercise handout. The document handout used by the Hands-On Group and PowerPoint file used by the Infographic Group are available in Supplementary Information.

The interactive infographics were constructed according to fundamental principles outlined by the Aesthetic Learning Experience Framework (Dunlap & Lowenthal, 2016; Parrish, 2007) and Cognitive Theory of Multimedia Learning (Mayer, 2002). Specific examples of application of principles from these frameworks are presented in Figure 1. Broadly, the infographics were designed to encourage active engagement, multi-sensory experiences, and providing contextualized learning experiences of basic physicochemical reactions in a visual manner. The subject matter and visual explanations within the infographics were constructed with the advice of an panel of subject matter experts and were revised multiple times to better utilize specific framework principles.

Results

Statistical Analyses

Changes in cheesemaking knowledge, self-efficacy, and learning style attitudes were analysed via a one-way ANOVA. These analyses were performed using JMP Pro 13 (SAS Institute Inc., Cary, NC). Effect sizes (Cohen's d) were calculated using R (version 3.3.2; R Core Team, 2016) and the *effect size* package (version 0.3.0; Ben-Shachar et al., 2020).

Pre-treatment Baseline

The demographic make-up of the two experimental groups was similar (Appendix A). No statistically significant differences were found between the Hands-On Group and Infographic Group in terms of age, sex, academic college, previous mozzarella making experience, and ethnicity. Moreover, average scores on the cheesemaking knowledge pretest evaluation were also statistically equivalent (p=0.76). These data indicate that the two experimental groups were consistent with each other during the pre-treatment phase of the experiment. The rather high scores on the pretest (approximately 50%) could be due to the inclusion of true/false questions in the evaluation. Four of the ten questions were true/false and could have been susceptible to

guessing, resulting in somewhat inflated pretest scores. Another possibility is that the relatively high amount of agriculture-focused students in each group (~60%) could have had some cursory knowledge of cheese/dairy technology from previous experience and coursework.

Cheesemaking Knowledge

After completion of the main experiment phase of the study, both groups experienced an increase in cheesemaking knowledge as determined by the posttest evaluation (Table 1). However, only the Infographic Group experienced a significant increase in cheesemaking knowledge with an increase of approximately two out of ten from pretest to posttest (*p*<0.0001; d=1.49). The Hands-On Group did not experience a statistically significant increase in cheesemaking knowledge (*p*=0.41; d=0.26). Standard deviations for both groups was approximately 1.0, indicating consistency within each group in completion of the posttest evaluation.

Table 1. Cheesemaking Knowledge Evaluation scores by treatment over the two study phases. Scores out of 10.

Group	Main Experiment				Follow-Up Experiment		
	Pretest	Posttest 1	Pre/Post Diff		Posttest 2	Post1/Post2 Diff	
	Mean ± SD		*p*	d	Mean ± SD	*p*	d
Hands-On Group	5.0 ± 1.2	5.3 ± 1.1	0.4059	0.26	6.9 ± 1.3	0.0008	1.32
Infographic Group	5.1 ± 1.1	6.9 ± 1.3	<0.0001	1.49	6.5 ± 1.4	0.4579	0.30

After completion of the follow-up experiment phase, the Hands-On Group (now having completed the Infographic lab after the Hands-On lab) had a statistically significant increase in cheesemaking knowledge (*p*=0.0008; d=1.32). The Infographic Group (now having completed the Hands-On lab after the Infographic lab) experienced a slight decrease in cheesemaking knowledge, although not to a statistically significant degree (*p*=0.46; d=0.30).

Given these data, the Infographic lab was shown to raise cheesemaking knowledge scores by a significant degree (approximately two letter grades). The Hands-On lab, however, failed to raise cheesemaking knowledge to a significant degree. When comparing posttest scores between the two groups, the Infographic Group experienced a statistical significantly larger knowledge gain than the Hands-On Group (*p*=0.0007; d=1.32). The follow-up experiment phase demonstrated that the Hands-On Group was able to achieve equal learning outcomes by completing the Infographic lab after completing the Hands-On lab.

Cheesemaking Self Efficacy

Cheesemaking Self Efficacy scores increased in both study groups during the main experiment phase by approximately three points (on 8-pt Likert-type scale), which was statistically significant (*p*<0.0001; see Table 2). When considering Cohen's d values both the Hands-On Group and Infographic Group demonstrated large effects, with the Infographic Group showing a larger effect than the Hands-On Group. Of note is the increase in self-efficacy of the Hands-On Group participants even though they did demonstrate a significant increase in cheesemaking knowledge (see above section). This could be indicative of a "false sense of security" conferred to participants by performing

traditional laboratory exercise consisting of hands-on activities, and will be discussed further in the Discussion section.

Table 2. Participant cheesemaking self-efficacy and learning modality opinion by timepoint. (8-pt Likert-type Scales; 1 = Strongly Disagree, 8 = Strongly Agree).

Evaluation	Main Experiment				Follow-Up Experiment		
	Pretest	Posttest 1	Pre/Post Diff		Posttest 2	Post1/Post2 Diff	
	Mean ± SD		*p*	d	Mean ± SD	*p*	d
Cheesemaking Self Efficacy Evaluation							
Hands-On Group	3.4 ± 1.7	6.2 ± 0.9	<0.0001	2.06	6.9 ± 0.7	0.0068	0.87
Infographic Group	3.2 ± 1.4	6.5 ± 0.8	<0.0001	2.89	7.2 ± 0.8	0.0121	0.88
I find hands-on exercises more beneficial to learning technical material than lectures							
Hands-On Group	6.9 ± 1.0	7.4 ± 0.8	0.0761	0.55	7.3 ± 0.7	0.6537	0.13
Infographic Group	6.6 ± 1.8	6.9 ± 1.4	0.5225	0.19	7.3 ± 1.0	0.3995	0.33
I find e-learning/point-and-click exercises useful to learning a topic							
Hands-On Group	4.8 ± 1.3	5.8 ± 1.2	0.0210	0.88	6.9 ± 1.1	0.0041	0.96
Infographic Group	4.6 ± 1.7	5.6 ± 1.8	0.1025	0.57	4.9 ± 2.5	0.3917	0.32

Cheesemaking Self Efficacy scores increased further after the follow-up experiment was complete, subsequent to both groups having completed both lab exercise types. Increases were statistically significant for both groups ($p > .05$).

Learning Modality Attitudes and Laboratory Impressions

After completion of the main experiment, both study groups' attitudes towards hands-on exercises and e-learning-type exercises increased (Table 2). However, only the Hands-On Group's attitude of e-learning exercises experienced a statistically significant increase, with a large effect size (p=0.02; d=0.88). This trend continued and increased in magnitude after completion of the follow-up experiment. The Hands-On Group, after completing the traditional lab exercised followed by the infographic lab, experienced a further increase (p=0.004; d=0.96). The Infographic Group did not experience statistically significant increases in attitude of hands-on and e-learning exercises during any phase of the study.

Impressions specific of both laboratory types are shown in Table 3. Two statistically significant increases were found. The Infographic Group indicated that they found that completing the Hands-on laboratory exercise further increased their mozzarella making knowledge (p=0.044; d=0.82) and the Hands-on laboratory was more stimulating than the Infographic lab (p=0.011; d=0.91). This outcome was further corroborated by the STEM Semantic Survey results (Appendix A), in which the Infographic Group found the Interactive Infographic Lab exercise to be more mundane than Hands-On Group (p=0.027). No other statistically significant differences were found between the two study groups in the STEM Semantic Survey results.

Discussion

Knowledge Transfer and Lab Exercises

Laboratory exercises are integral parts of many different curricula and provide valuable contextualization of content across a wide variety of technical disciplines. This is particularly important in the realms of food and agriculture due to pronounced lack of

"food literacy" that exists in the wider science literacy deficit (Pray, 2016). One way to address this is by training the next generation of food technologists via innovative methods that will yield a robust workforce ready to take on this challenge. Food production often takes place on large scales with expensive equipment beyond the means of many academic courses and laboratory exercises. "Virtual" laboratory exercises can help remedy these issues. These types of activities have risen in popularity as of late in fields such as engineering and science (Chan & Fok, 2009; Wolf & Member, 2010). Agriculture virtual modules are also being developed to teach students topics such as animal rearing and management (Erickson et al., 2019). However, a dearth of knowledge still exists with regards to virtual and online exercises that specifically address subjects such as food-manufacturing, food technology, and food physicochemical phenomena. The study presented here demonstrates the value such exercises can have in addressing this gap.

An important novel consideration when designing laboratory exercises for future instruction is the ability for them to be delivered remotely, virtually, or in a socially distant manner. At the writing of this manuscript, many traditional laboratory exercises are not able to occur due to health and safety challenges presented by COVID-19. Virtual lab exercises are one route forward. The virtual lab exercise presented in this paper highlights the novel use of interactive infographics and demonstrates effective knowledge gain by student participants.

Infographic Model and Visual Aesthetics

The infographic tools constructed for this study demonstrated the effectiveness of multimodal learning in a food science laboratory setting. Students demonstrated higher knowledge gains after completing the infographic tool session compared to those who engaged in the traditional hands-on learning activity. However, this knowledge gap was eliminated when the hands-on group later completed the infographic tool session. Additionally, students also reported higher interest/engagement with the hands-on learning that required them to physically enact the chemical changes that the infographic tool simply depicted. Although it was not the main focus of this study, it is important to note situational interest is an important factor of students' prolonged learning (Durik & Harackiewicz, 2007). Given the low cost of implementation, the role of infographic learning may be approached as complementary to traditional, hands-on learning, which provides experience not measured in semantic knowledge. This fact is further stressed by differences in learner satisfaction presented within this study; students found the traditional exercises to be more stimulating even at the expense of declarative knowledge outcomes.

An additional component of instruction captured with the infographic model was the use of visual aesthetics via illustrations and animations. Verbal and written feedback from the students indicated that the pictures and illustrations used to demonstrate the chemical and physical phenomena occurring within cheesemaking added an additional learning opportunity that was missing from the traditional exercise. One student indicated that the virtual lab allowed them "to see and think about what was occurring at the molecular level" during the cheesemaking process, and the traditional lab did not elucidate that level or depth of thought.

Conclusions, Limitation, and Future Work Direction

This study demonstrated improved learner outcomes for a topic area within food science and agriculture education when interactive infographics were used versus a traditional laboratory exercise. However, the subject matter itself was specific to dairy chemistry and cheesemaking technology. In addition, the sample size used in this study was limited due to the specificity of the course in which it was conducted. Future work should aim at approaching other subjects from different fields in a similar matter with a larger number of students. Broader subjects such as biology and/or chemistry should be well suited to infographic-type learning tools considering introductory topics in these fields usually focus on explaining common phenomena that form the foundation for more complicated material taught at a later time.

Future studies should consider the supplementary role of students interacting with infographics and other virtual learning environments in learning contexts. Self-guided and instructor-free infographic tools should facilitate other types of procedural, process-oriented, and scientific phenomenon in other domains. Given the benefits of presenting information in multiple modalities and low cost of implementation, infographic tools might provide a beneficial supplement to instructors teaching complex phenomenon across all domains. Additionally, more work is needed to delineate between the specific factors present in infographics that increase students' learning outcomes. In sum, the current study demonstrated that an infographic learning tool provided greater knowledge gains than a traditional hands-on learning experience currently utilized in university laboratory settings. Students reported higher knowledge gains through the encoding of visual, textual, and auditory information present in the infographic learning tool.

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Appendix A

Demographic information for the participants in the study. N=35.

Demographic		n	%
Age	20.5 ± 2.2		
Sex	F	19	54%
	M	16	46%
Academic Major	Agriculture	21	60%
	Business	1	3%
	Engineering	4	11%
	Science	8	23%
	Technology	1	3%
Ethnicity	African American	2	6%
	Asian	5	14%
	Latino	3	9%
	Multiracial	3	9%
	White	22	63%
Have Made Mozzarella Before?	No	31	89%
	Yes	4	11%

Internal consistency measures for the instruments developed for this study.

Instrument	Cronbach's α
Cheesemaking Knowledge Evaluation	0.81
Cheesemaking Self Confidence Evaluation	0.82
Learning Modality Attitudes and Impressions – Pretest	0.73
Learning Modality Attitudes and Impressions – Posttest 1 &2	0.76

Pre-experiment baseline data for participants who took part in this study.

Metric	Hands-On Group (N=18)	Infographic Group (N=17)	Difference
	Mean ± SD		P
Pretest – Cheesemaking Knowledge (out of 10)	5.0 ± 1.2	5.1 ± 1.1	0.7645
Age	20.3 ± 1.7	20.8 ± 2.6	0.5652
Sex	Female = 11 Male = 7	Female = 8 Male = 9	0.4042
Academic College	Agriculture = 10 Business = 1 Engineering = 2 Science = 5 Technology = 0	Agriculture = 11 Business = 0 Engineering = 2 Science = 3 Technology = 1	0.6409
Previous Mozzarella Experience	Yes = 3 No = 15	Yes = 1 No = 16	0.3162
Ethnicity	African American = 1 Asian = 1 Latin = 1 Multi-racial = 1 White = 13	African American = 1 Asian = 4 Latin = 1 Multi-racial = 2 White = 9	0.5301

STEM Semantic Survey results by group. (8-pt Scales).

Word Pair	Hands-On Group (N=18)	Infographic Group (N=17)	Difference
	Mean ± SD		P
After Hands-On Lab			
1=fascinating, 8=mundane	1.8 ± 1.3	1.7 ± 0.9	0.7463
1=appealing, 8=unappealing	2.0 ± 1.7	1.6 ± 0.8	0.3950
1=exciting, 8=unexciting	2.3 ± 1.9	2.1 ± 1.4	0.7161
1=means nothing, 8=means a lot	6.3 ± 1.7	7.1 ± 0.9	0.111
1=boring, 8=interesting	7.0 ± 1.7	7.4 ± 0.6	0.3661
After Interactive Infographic Lab			
1=fascinating, 8=mundane	3.7 ± 1.4	5.2 ± 2.3	0.0266
1=appealing, 8=unappealing	3.9 ± 1.7	4.8 ± 2.3	0.2149
1=exciting, 8=unexciting	4.5 ± 1.5	5.2 ± 2.0	0.2371
1=means nothing, 8=means a lot	6.1 ± 1.7	5.2 ± 1.9	0.1744
1=boring, 8=interesting	5.2 ± 2.0	4.5 ± 2.2	0.3454