Genetic Engineering Online Lesson Leads to Increased Knowledge and More Accepting Student Attitudes[1]

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Abstract

Genetic engineering has been used to aid production of many high acreage crops in U.S. agriculture for nearly three decades. Despite this use of genetic engineering to create widely grown crops that are classified as GMOs (genetically modified organisms), skepticism of this technology is prevalent and consumer attitudes have not become more accepting over time. There are many factors that contribute to an individual's attitude toward genetic engineering, such as knowledge level, risk/benefit perception, background (urban vs. rural), gender and trust of government safety regulation. An online resource known as *The Journey of a Gene* was recently developed to teach the process of genetic engineering and address attitude factors. This study was designed to test the impact of the online resource on student knowledge and attitudes. By surveying nearly 900 students, we found that the online resource was effective in increasing student knowledge and shifting student attitudes to become more accepting of genetic engineering technology. This increase in accepting attitudes varied by gender, background and trust in government safety regulation. Our results demonstrate that genetic engineering attitudes are not static among young learners and the use of online, science-based learning resources can promote a more informed generation of consumers.

Introduction

Although genetically engineered crops or GMOs have been a part of the world food system for nearly three decades, some consumers are still skeptical of the technology. Crop genetic engineering is the manipulation of a plant's DNA in order to improve crop management or end use qualities of the crop. Genetic engineering is commonly done by inserting genes from a source other than the crop plant to encode proteins that perform a novel function. Another common genetic engineering technique involves new gene insertion to block the expression of a gene that already exists in the plant. Over 90% of the soybeans, corn and cotton planted in the U.S. have been genetically engineered, primarily to benefit farm production (Fernandez-Cornejo, 2014). Papaya, rice and canola crops have also been commercialized with genetically engineered events and are currently available on the U.S. market.

Experts in biotechnology have long assumed that consumer attitudes towards genetic engineering would become more accepting over time, gradually diminishing in skepticism and risk perception while embracing the use of genetic engineering technology in our food system. However, consumer attitudes have not changed much since the entry of genetically engineered foods to the marketplace (Frewer et al., 2013). Many studies have found a positive correlation between knowledge of science or biotechnology and accepting attitudes towards genetic engineering (Mowen et al., 2006; Tegegne et al., 2013; Fonseca et al., 2012; Mowen et al., 2007; Sohan et al., 2002). A meta-analysis has indicated that a positive correlation between knowledge and attitudes holds across contexts and cultures (Allum et al., 2008). In addition to knowledge, an individual's attitude toward genetic engineering can be shaped by their view of the benefits and the risks of genetic engineering for their health, the environment and the economy.

Few studies have been conducted to directly link instructional practices with learner attitudes about genetic engineering. Our goal was to develop a resource that teachers could easily adopt and incorporate into classrooms. Our team designed *The Journey of a Gene* (passel.unl.edu/ge), an online educational tool built to teach the steps required to produce a genetically engineered crop. *The Journey of a Gene* presents learning through a problem-solving context and focuses on the story of developing disease-resistant soybeans for farmers. This resource organizes the science and technology of the genetic engineering process into four

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main steps. Within each step, students can view short videos and animations to learn the information needed to understand each step of genetic engineering. Each section concludes with a video of a scientist who takes the students into their lab, greenhouse or field to share how the step is done. The online learning environment also includes a section on risks and benefits which provides instruction on food safety testing for GMOs and shares video testimonials representing arguments both for and against the application of genetic engineering in our food system. Integrating this instructional resource into high school or entry-level college curriculums could educate future consumers.

This study was done to test the hypothesis that student use of *The Journey of a Gene* as a learning resource would lead to a more accepting attitudes toward genetic engineering. A survey measuring attitudes towards genetic engineering was given to nearly 900 students in one high school course and four college science courses. Half of the students took the survey before receiving the educational treatment (pre survey/control group) and the other half took the survey after receiving the educational treatment (post survey/treatment group) and the scores of these groups were compared.

Methods

Population and Treatment

The sample population and sampling frame for this study included four college science courses (biology, genetics, plant science and biotechnology) taught at the University of Nebraska-Lincoln and one Iowa high school course (biotechnology) during the fall semester of 2014. The courses were chosen based on relevance of the genetic engineering lesson material to the course content. The participating courses represented a diverse population of students based on class standing and professional goals. The introductory biology course included 689 students who were primarily college freshman and sophomores from all science and non-science majors. The genetics course was comprised of 29 students who were sophomores through seniors in agriculture-related majors. Similarly, the 71 participants in the plant science course were primarily freshman in agriculture-related majors. The biotechnology course was an online class that included 32 students and incorporated a wide variety of majors and including freshman to seniors and non-traditional students. The high school course was a biotechnology class and was comprised 21 of junior and senior students primarily from agricultural backgrounds. Altogether, the sample of these five courses was nearly 900 student participants. The instructors who taught these biology-related courses incorporated *The Journey of a Gene* content voluntarily. The deployment of the *The Journey of a Gene* as a learning treatment was timed to fit with the topic learning schedule in the course.

Variables and Measures

The dependent variables measured in this study were 1) attitudes towards genetically engineered organisms (GMOs) and 2) knowledge about the process of creating GMOs. The independent variable was an educational treatment, *The Journey of a Gene* educational module.

To measure these variables, a survey was adapted from two existing survey instruments: Sohan et al. (2002) and the Eurobarometer (http://ec.europa.eu/public_opinion/archives/ebs/ebs_341_en.pdf). The Sohan instrument was designed to correlate prior knowledge with attitudes. It was modified to fit the current study by writing new knowledge questions to reflect the use of *The Journey of a Gene*. This was accomplished by replacing the six current event multiple choice questions in the Sohan survey with 13 true/false questions reflecting the process of genetic engineering (Table 2). The new questions were general in nature such that individuals who already were familiar with genetic engineering would be able to answer the questions correctly. The Eurobarometer is well established as an instrument to measure the consumer attitudes toward genetic engineering. The Sohan and Eurobarometer instruments were combined by entering both survey instruments into a single online survey using SurveyMonkey, an online survey software.

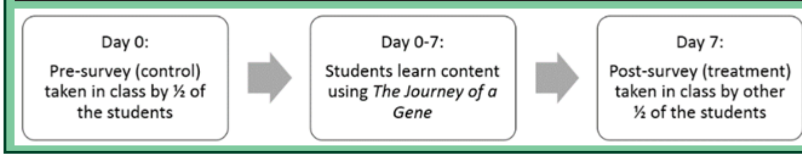
Using the Sohan and Eurobarometer survey instruments together, attitude was measured using 43 attitude statements (Table 4) that were rated on a 4-point Likert-type scale. The response options were strongly disagree, disagree, agree and strongly agree. The attitude questions encompassed the following major components of attitude: impact on environment, impact on health, fear, impact on the economy, emotion, usefulness and risk perception.

To describe and differentiate the survey population, demographic data was collected on the participants, including gender, childhood surroundings (urban or rural), degree program and whether they trust government safety regulations. These demographics were also used as possible attitude-affecting factors (Table 5).

Validity, Reliability and Pilot Study Procedures

Several measures were taken to maximize the validity and reliability of the questionnaire before the study commenced. Non-experts who were similar to the sampling frame reviewed the survey to provide face validity. These individuals provided details about the survey design, readability, ease of completion and understandability. Review of the instrument was also done by relevant experts, which included an educational researcher, genetic engineering expert, genetics professor and statistician to provide content validity. Cognitive interviews were also conducted with two individuals similar to the survey population to identify design flaws and potential points of confusion that could affect data collection. In addition, the instrument had already been tested in two prior studies in different contexts. Since the instrument contains several questions relating to each construct, reliability was measured with Cronbach's alpha. The attitude survey, consisting of 48 items, was found to be reliable in a post-hoc analysis with an alpha level of 0.960. The knowledge survey, consisting of 13 items, had an alpha level of 0.413.

Figure 1. Data collection timeline



Survey Procedures

The Journey of a Gene online resource was incorporated into the lab or recitation sections in each of the courses described as approved by the University of Nebraska Institutional Review Board (IRB). Students were divided into pre (control) and post survey (treatment) groups by lab sections. The groups were assigned so that an equal number of sections offered at certain time slots would be distributed between the treatment and control groups to make the groups as similar as possible. In addition, if a teaching assistant (TA) taught two sections, one section was placed in the treatment group and one section was placed in the control group in order to minimize teacher effect. TAs were trained by the research team on the implementation of the survey and *The Journey of a Gene* resource one week prior to implementation of the study. Students were required to use an e-mail feature in the resource to report their quiz scores to their teacher for each of the four sections of the resource before coming to class. Students were given time to take the online survey during class to minimize non-response error. On the first page of the survey, students were presented with an online version of the informed consent form where clicking 'next' to begin the survey indicated their consent. Students were also reminded by their TA that their participation was voluntary and anonymous.

Implementation of the study varied by class to fit the course curriculum. Once the study began, it was completed within an eight-day period. The lab and recitation sections assigned to the pre group did not receive instruction on genetic engineering prior to taking the survey. The pre survey group sections took the survey on the first day of the study. Following this lab session, all students were given one week to go through *The Journey of a Gene* educational treatment as a homework assignment. The post survey group had studied *The Journey of a Gene* the week prior to taking the survey on the last day of the study (Figure 1). The design allowed each student to receive an equal educational experience.

Data Analysis.

To analyze the data from the survey instrument, the data was coded numerically in the survey software (SurveyMonkey). The Likert scale enabled participants to have a numerical score representing how accepting their attitude was toward application of genetic engineering and their understanding of the science facts that underpin genetic engineering technology. The attitude scores were reported as a cumulative score of all 48 attitude questions. Each attitude question received a score of 1-4, with 1 being least accepting and 4 being most accepting. The knowledge scores were reported by the percent of questions answered correctly out of 13. Incomplete surveys with missing values were removed from the data set. Some questions were also reverse coded so that all answers were measured on the same scale. The data were analyzed using SAS 9.4 (SAS Institute, Cary, NC). The pre and post survey group scores were compared using a two-tailed paired t-test (α=0.05). Paired t-tests were run to analyze whether the treatment effect was greater for certain demographics in the population.

Results

Knowledge about Genetic Engineering

To determine the impact of *The Journey of a Gene* on knowledge of genetic engineering, a two-tailed t-test was used to compare knowledge scores between pre and post survey groups. The post survey group had higher knowledge scores than the pre survey group and the difference between these groups was significant (Table 1). The Cohen's D standardized effect size was 0.53. Although the post survey group averaged only one additional correct answer than the pre group, the increase in score was contributed by increases in all 13 of the knowledge questions (Table 2). The increase in score across questions suggests that the online learning through *The Journey of a Gene* was effective in improving basic knowledge about the genetic engineering.

Attitudes toward Genetic

To determine the effect of *The Journey of a Gene* online resource on student attitudes toward genetic engineering, a two-tailed t-test was used to compare attitude scores from the pre and post groups. More accepting student attitudes were found in the post group; this difference was statistically significant (Table 3). The Cohen's D standardized effect size was 0.25. The shift to more accepting attitudes held true in all but five of the forty-eight individual attitude questions (Table 4). This result indicates that *The Journey of a Gene* resource resulted in a significant shift in attitudes toward genetic engineering.

Attitude Differences by Group

Table 1. Mean Group Scores on Knowledge Questions on the Science and Technology of Genetic Engineering

	Group Score*	SE	Lower	Upper	p
Pre (Control)	62.33	0.61	61.12	63.53	
Post (Treatment)	70.20	0.65	68.91	71.46	< .0001

*Scores reported as a percent correct out of 13 knowledge questions.

Table 2. Genetic Engineering Science and Technology Knowledge Questions and Mean Scores in Pre and Post Survey Groups

	Correct Answer	Percent of Students Answering Correctly Pre	Percent of Students Answering Correctly Post	Difference
Genetic engineering can be used to move a gene between any two organisms.	T	79	89	9.80 *
Genetic engineering has replaced traditional cross breeding in the majority of crop variety development.	F	35	38	3.39
There are organisms that move their genes into other unrelated species in nature.	T	63	65	1.83
Food safety testing is not done until after a genetically engineered crop is already on the market.	F	79	86	7.06 *
Genetic engineering involves changing a large portion of an organism's genetic makeup.	F	65	79	14.08 *
Genetic engineering is done by injecting new genes into seeds before the farmer buys them.	F	34	40	5.97
Genetically engineered plants can only reproduce by cloning.	F	76	81	4.68
Genes can be transferred between species because the genetic code is a universal language across species.	T	59	85	25.02 *
Genetic engineers can select the exact location where a new gene is inserted in a genome.	F	20	25	5.14
Genetic engineers will know what protein is encoded by the gene before they ever insert it.	T	75	83	8.47 *
Genetic engineering changes a single plant cell, which is then grown in to a whole plant.	T	75	81	6.58 *
Once a gene is inserted into a plant it becomes hidden and scientist cannot detect its presence.	F	84	88	4.45
Science has not progressed enough that the genetic engineer can control where the inserted gene is expressed.	F	68	72	3.65

*Indicates the difference between the percentage of correct answers in the pre and post groups is significant at a level of α=.05. The color in the difference column increases with intensity to indicate larger differences between pre and post group scores.

Previous studies have indicated differences in attitude toward genetic engineering associated with gender, urban vs. rural background, trust in government safety regulation and genetic engineering information source. To investigate whether these group differences existed in the student population and to determine if *The Journey of a Gene* had a greater impact in certain groups, two-tailed independent t-tests were used to compare the pre and post groups. Males were significantly more accepting of genetic engineering than females in both the pre group and the post group (Figure 2a and Table 6). The higher score for accepting attitude for females in the post group over the pre group was statistically significant (p=0.0008) while the higher attitude scores for males was not statistically different than the pre scores. Students from rural backgrounds were significantly more accepting of genetic engineering than students from urban backgrounds in both the pre and post groups (Table 6 and Figure 2b). The treatment effect, however, was approximately equal between the groups as indicated by the similar difference between group mean attitude scores pre and post (pre= 7.3833, SE=1.7878, post=7.1204, SE=2.0109). Similar results were found based on trust of government safety regulation. Students who indicated trust in government safety regulation had significantly higher scores than students who distrusted government safety regulation in the pre and post groups (Table 6 and Figure 2c). The treatment impact between pre and post within the trust and distrust groups was not statistically measurable.

Table 3. Mean Group Scores on Acceptance of Genetic Engineering in the Food System , Attitude Questions

	Group Score*	SE	Lower	Upper	p
Pre (Control)	117.09	0.90	115.33	118.86	
Post (Treatment)	121.70	1.01	119.73	123.68	0.0007

*Scores reported as a total score compiled from all 48 knowledge questions. Each attitude question which ranged from score of 1 (least accepting) to 4 (most accepting) on a Likert scale.

Table 5. Demographics of the Respondents from the Life Science Courses in this Study

		Number of Respondents Pre	Number of Respondents Post
Gender	Female	277	223
	Male	195	158
Student Background	Rural	219	161
	Urban	253	219
Primary Source of Knowledge	Blogs	21	16
	College	166	189
	Friends	95	46
	News	160	121
Trusting of Government	Trust	294	280
	Distrust	178	98

Table 6. Differences of Attitude Mean Scores by Demographic Group Among the Life Science Course Students in this Study

Treatment	Group	Group Score*	SE	Lower	Upper	p
Pre	Female	112.51	1.15	110.26	114.76	
	Male	123.84	1.36	121.16	126.51	
	Comparison	-11.33	1.78	-14.82	-7.83	<.0001
Post	Female	118.30	1.28	115.80	120.81	
	Male	126.84	1.52	123.87	129.82	
	Comparison	-8.54	1.98	-12.43	-4.65	<.0001
Pre	Rural	121.15	1.31	118.58	123.72	
	Urban	113.76	1.22	111.37	116.15	
	Comparison	7.38	1.79	3.87	10.89	<.0001
Post	Rural	126.01	1.53	123.01	129.00	
	Urban	118.89	1.31	116.32	121.45	
	Comparison	7.12	2.01	3.17	11.07	0.0004
Pre	Distrust government	104.04	1.29	101.51	106.57	
	Trust government	125.15	1.00	123.18	127.12	
	Comparison	-21.11	1.63	-24.31	-17.91	<.0001
Post	Distrust government	106.70	1.73	103.30	110.11	
	Trust government	127.25	1.03	125.24	129.27	
	Comparison	-20.55	2.02	-24.50	-16.59	<.0001

Discussion

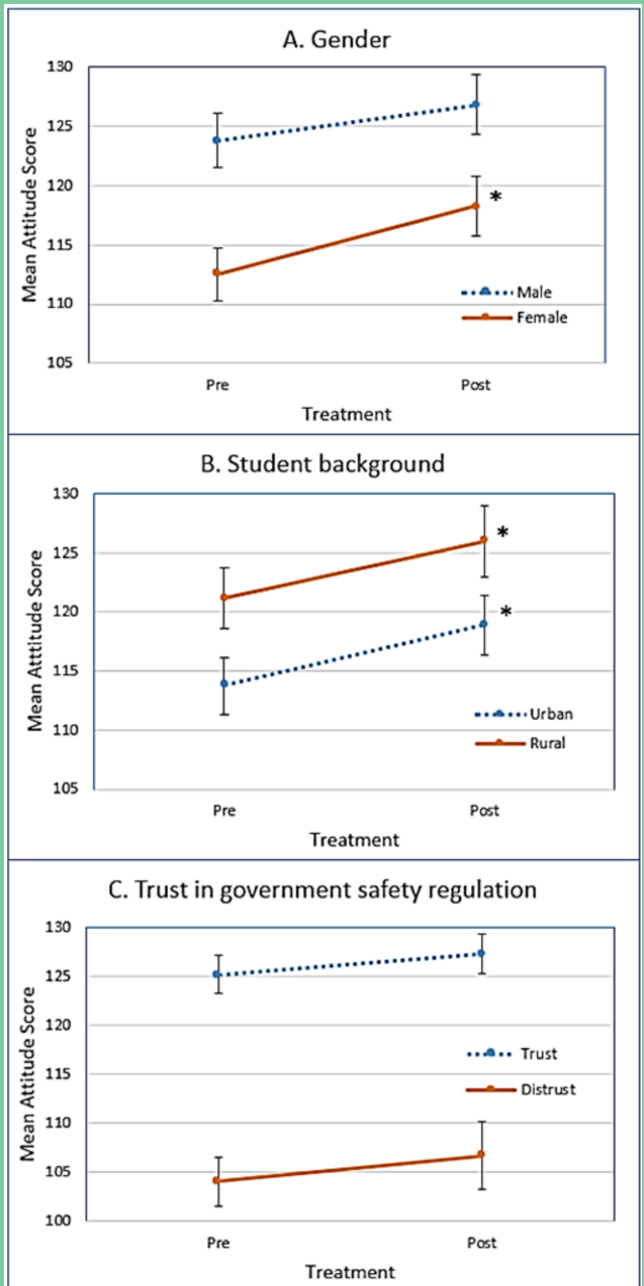
Our results demonstrate that genetic engineering attitudes are not static among learners who are at or entering the young adult consumer demographic. This study also supports

Table 4. Acceptance of Genetic Engineering in our Food System Attitude Questions and Mean Scores in Pre and Post Survey Groups

For each of the following issues regarding GM food please tell me if you agree or disagree with it.	Average Pre Score	Average Post Score	Difference	
GM food is good for the US economy	2.91	3.07	0.16	*
GM food is not good for you and your family	2.66	2.81	0.15	*
GM food helps people in developing countries	3.06	3.18	0.12	*
GM food is safe for future generations	2.64	2.92	0.28	*
GM food benefits some people, but puts others at risk	2.40	2.32	-0.09	
GM food is fundamentally unnatural	2.30	2.47	0.18	*
GM food makes you feel uneasy	2.73	2.94	0.21	*
GM food is safe for your health and your family's health	2.61	2.87	0.26	*
GM food does no harm to the environment	2.43	2.59	0.16	*
The development of GM foods should be encouraged	2.68	2.93	0.25	*
The first way is to artificially introduce a resistance gene from another species such as a bacterium or animal into an apple tree to make it resistant to mildew and scab. For each of the following statements about this new technique please tell me if you agree or disagree.				
It is a promising idea	3.04	3.19	0.15	*
Eating apples produced using this technology will be safe	2.69	2.81	0.12	*
It will harm the environment	2.68	2.81	0.14	*
It is fundamentally unnatural	2.37	2.50	0.13	*
It makes you feel uneasy	2.66	2.83	0.16	*
It should be encouraged	2.71	2.83	0.13	*
The second way is to artificially introduce a gene that exists naturally in wild crab apples which provides resistance to mildew and scab. For each of the following statements about this new technique please tell me if you agree or disagree.				
It will be useful	3.18	3.31	0.13	*
It will be risky	2.61	2.66	0.05	
It will harm the environment	2.84	2.89	0.05	
It is fundamentally unnatural	2.59	2.65	0.06	
It makes you feel uneasy	2.81	2.94	0.12	*
It should be encouraged	2.89	2.98	0.10	*
It is acceptable to direct the genetic material of an organism by:				
inserting a foreign gene	2.47	2.70	0.23	*
blocking the expression of an existing gene	2.76	2.83	0.08	
using selective breeding programs	2.96	3.04	0.08	
using artificial insemination	2.67	2.68	0.01	
It is acceptable to combine genes between:				
the same plant species	3.16	3.21	0.04	
different plant species	2.84	2.98	0.13	*
the same animal species	3.07	3.07	0.00	
different animal species	2.50	2.57	0.07	
plants and animals	2.21	2.28	0.08	
For each item below, please indicate the level to which to agree or disagree.				
Genetically altered foods should be labeled.	1.84	1.83	-0.01	
Genetically altered foods are superior to traditionally bred foods.	2.28	2.25	-0.03	
Genetic engineering may alleviate world food shortages.	3.03	2.99	-0.03	
It is acceptable to genetically engineer plants for food.	2.85	2.98	0.13	*
Genetically altered organisms such as animals are safe to eat.	2.53	2.62	0.09	
For each item below, please indicate the degree to which you agree or disagree.				
Genetically altered organisms disrupt the balance of nature.	2.43	2.55	0.13	*
Genetically altered organisms present a health hazard.	2.62	2.63	0.01	
The risk of genetic engineering is outweighed by the benefits.	2.50	2.57	0.08	
The risk of genetic engineering is minimal due to strict safety regulations.	2.57	2.77	0.19	*
Genetic engineering may contribute to the disappearance of small farms.	2.14	2.32	0.18	*
Genetic engineering may enhance the quality of life for all Americans.	2.59	2.69	0.11	*
Genetic engineering may create new job opportunities.	2.96	2.97	0.01	

*Indicates the scores between the groups are significantly different at a level of α≤.05. Scores for each attitude question ranged from score of 1 (least accepting) to 4 (most accepting) on a Likert scale. If a question was asked in the negative, the scale was corrected so a higher score would always indicate a more accepting attitude.

Figure 2. Attitude scores by treatment and demographic.



Demographics: A) gender, B) student background, C) trust in government safety regulation. The pre treatment group represent students in the control group who had not used *The Journey of a Gene* educational treatment before taking the attitude survey. Post treatment group represents students whohad received the treatment before taking the attitude survey. Higher attitude scores represent student attitudes that are more acception of genetic engineering technology. All differences between scores by demographic represented in A-C are significant at a level of α=.05.

*Indicates the pre-post difference within the demographic is significant a level of α=.05.

the premise that learners can advance their understanding of the science that underpins genetic engineering and the differences between foods from GMO vs. non GMO crops by working with online learning resources that are appropriately crafted and integrated into life science courses. The shift in attitudes toward approving this technology in our treatment group is consistent with other studies that demonstrate a link between science understanding and the acceptance of GMO technology.

Many factors can impact the relationship between knowledge and accepting attitudes. These factors include trust in regulators (Qiu and Huang, 2006; Moon and Balasubramanian, 2004; Brossard and Nisbet, 2007; Priest et al., 2003; Hossain and Onyango, 2004), media coverage (Priest, 2001; Brossard and Nisbet, 2007; Hoban, 1998; Fritz et al., 2004), gender (Brossard and Nisbet, 2007; Hossain and Onyango, 2004; Mowen et al., 2006; Sohan et al., 2002), risk/benefit perception (Brown and Ping, 2003; Moon and Balasubramanian, 2004; Falk et al., 2002; Lusk et al., 2004; Lusk et al., 2005; Frewer et al., 2013), rural vs. urban background (Mowen et al., 2006; Tegegne et al., 2013), area of study (Sohan et al., 2002; Tegegne et al., 2013; Fonseca et al., 2012; Lamanauskas and Makarskaitė-Petkevičienė, 2008) and education level (Allum et al., 2008; Saad, 2001). All of these factors may contribute to the development of attitudes toward genetic engineering to varying degrees.

Trust, demographics, risk-benefit perception and knowledge have a combined, complex impact on an individual. The factor of knowledge, however, is the most pliable and realistically changed. For example, after a small biotechnology lesson, Minnesota high school students indicated they felt more positively about the use of genetic engineering in food production (Reicks et al., 1996). Similar results were found with a group of Virginia high school students who participated in a two-week biotechnology curriculum (Stotter, 2004)

Greater acceptance among post survey participants over pre survey participants indicates that *The Journey of a Gene* educational treatment likely influenced student attitudes to become more accepting of genetic engineering (Table 2). Our result is consistent with other educational interventions (Reicks et al., 1996; Stotter, 2004). The increase in attitude score was relatively small: 4.61 points on a 172-point attitude scale. Given *The Journey of a Gene* resource was implemented as homework which inherently comes with high degree of student choice, the impact on attitude reveals a high potential influence of education on this population. An attitude shift for high school or college students is important as these students are future household purchasers of food.

We also showed an increase in knowledge scores with the treatment (Table 1). Our knowledge questions were intended to measure what students knew about every step of the genetic engineering process. The questions also addressed some common misconceptions. Therefore, not all of the questions would necessarily fit within the same construct. The Cronbach's alpha reliability of the knowledge instrument was 0.413, however this measure assumes that all the questions are measuring a single construct. In a post-hoc analysis we found that there were likely three factors represented in our knowledge instrument. It is likely that there are actually multiple factors involved in a complete understanding of the process of genetic engineering. Thus, our knowledge questions may still be practical for indicating an increase in understanding of many of the dimensions of the process of genetic engineering.

The Journey of a Gene's positive impact on attitude was likely a result of addressing a combination of the reported effectors of attitude, such as knowledge and risk-benefit perception. First, *The Journey of a Gene* most purposefully addressed knowledge, which is a well-supported contributor to accepting attitudes (Mowen et al., 2006; Tegegne et al., 2013; Fonseca et al., 2012; Mowen et al., 2007; Sohan et al., 2002; Allum et al., 2008). Although there are many content areas that could be addressed, *The Journey of a Gene* specifically worked to increase knowledge of the scientific process of creating a genetically modified crop. Another contributor to attitude, risk-benefit perception, (Brown and Ping, 2003; Moon and Balasubramanian, 2004; Falk et al., 2002; Lusk et al., 2004; Lusk et al., 2005; Frewer et al., 2013) was addressed in *The Journey of a Gene's* case study format. The case study format gave students insight into a current real-world soybean disease problem and introduced them to a farmer who would directly benefit from a genetic engineering solution. The case study approach gives students a view into the benefits of genetic engineering technology which they may not otherwise see directly.

The Journey of a Gene had the potential to impact many of the factors of attitude, but it affected students to different degrees based on their demographic. For example, females were less accepting of genetic engineering than males, which is consistent with previous studies (Brossard and Nisbet, 2007; Hossain and Onyango, 2004; Mowen et al., 2006; Sohan et al., 2002). When males and females of different college majors were compared, females enrolled as education majors were the least accepting of genetic engineering (Sohan et al., 2002). Additionally, teacher attitudes toward content are known to impact the attitudes of their students (Lock et al., 1995). Therefore, informing future teachers who will shape perceptions of the next generation of consumers is important. Future work should investigate how tools like *The Journey of a Gene* can better inform pre-service teachers.

Another demographic that we found represented a difference in attitude score was the level of trust in government safety regulation, which is also a known factor of attitudes toward genetic engineering (Qiu and Huang, 2006; Moon and Balasubramanian, 2004; Brossard and Nisbet, 2007; Priest et al., 2003; Hossain and Onyango, 2004). *The Journey of a Gene* resource had the potential to impact students' trust of government safety regulation by using videos to introduce students to the scientists behind the process of genetic engineering. By giving students insight into the safety testing of genetically engineered products, *The Journey of a Gene* had the potential to minimize perceived risk and increase trust. Not only do students hear the stories of scientists who produce genetically engineered products, but a section of *The Journey of a Gene* also focuses on the food safety regulation process required for genetically modified products. In our study, students who trusted government safety regulation had significantly higher scores than those who did not in both the pre and post survey (Table 6 and Figure 2), which is supported by previous works (Qiu and Huang, 2006; Moon and Balasubramanian, 2004; Brossard and Nisbet, 2007; Priest et al., 2003; Hossain and Onyango, 2004). Students who trusted the government safety regulation had the most accepting attitudes of the three demographics in both pre and post surveys, with the treatment having no statistically measurable effect. Students who distrusted government safety regulation had the lowest acceptance score of all the demographics groups (Table 6). Distrusting students in the post group were similarly unaccepting of genetic engineering after the treatment. Both trusting and distrusting groups held strong opinions. Neither group showed a significant change in attitude score in response to *The Journey of a Gene*. The consistent opinions of the students may indicate that trust is very difficult to effect through a short video series like the one presented in this study. The large difference in attitude scores between trusting and distrusting students may also indicate that trust is a particularly strong contributing factor toward the formation of attitudes toward genetic engineering. It could be advantageous to learn whether increased knowledge about the regulation process would lead to a greater trust and in turn an increase in accepting attitudes.

We also found that urban students were less accepting of genetic engineering than rural students, which is consistent with previous studies (Mowen et al., 2006; Tegegne et al., 2013). Although the study population included a wide variety of academic majors from urban and rural backgrounds, the study was conducted in Iowa and Nebraska, where the economy is agriculturally driven. Future investigation is needed to reveal whether the trends reported in this study hold true in other regions of the country that have fewer agricultural ties. Future studies that investigate urban settings will be important to reflect the national trend where a smaller and smaller proportion of the population is directly connected to agriculture (Alig et al., 2004).

If education truly leads to greater public acceptance, increasing educational efforts could prevent genetically engineered products from being held back by public protest, as occurred with the release of golden rice which was nutritionally enhanced for vitamin A using genetic engineering (Paine et al., 2005) as well as with Enviropig which was engineered to create less phosphorus pollution (Yang et al., 2008; Forsberg et al., 2013). Education has the potential to help ensure scientists and breeders will be able to continue to implement genetic engineering as a strategy to solve complex agricultural problems.

The increase in accepting attitudes between the pre and post survey groups in this study furthers our understanding of the potential for change in consumer attitudes toward genetically engineered foods. It indicates that individuals who invest time to learn more about the science of genetic engineering have more accepting attitudes towards genetic engineering technology. If scientists and plant breeders intend to continue to use genetic engineering to solve problems in our food system, it is important to incorporate learning resources such as *The Journey of a Gene* into classrooms. Education is a key component to help consumers make informed decisions about purchasing products derived through genetic engineering and make societal decisions about advancing genetic engineering research.

Summary

In this study, we demonstrated that *The Journey of a Gene* (passel.unl.edu/ge) online resource was effective in increasing student knowledge and shifting student attitudes to become more accepting of genetic engineering technology. This increase in accepting attitudes varied by gender, background, trust in government safety regulation and primary information source. Our results demonstrate that genetic engineering attitudes are not static, but can become more positive through education. This result provides motivation to integrate genetic engineering education into high schools, thus creating a more informed generation of consumers.

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