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A randomized controlled trial of an online immunization curriculum

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ABSTRACT

Introduction: Immunization education for physicians-in-training is crucial to address vaccine concerns in clinical practice. Vaccine education is not standardized across residency programs. The Collaboration for Vaccination Education and Research (CoVER) team developed an online curriculum for pediatric (Peds) and family medicine (FM) residents.

Methods: A cluster randomized controlled trial (RCT) was performed during the 2017–2018 academic year to evaluate the CoVER curriculum. A convenience sample of residency institutions were randomly allocated to the intervention or control group, with stratification by residency type. The intervention, the CoVER curriculum, consisted of four online modules and an in-person training guide. Control sites continued with their standard vaccine education. Pre-intervention and post-intervention surveys were emailed to residents in both groups. The primary outcomes compared between groups were changes in "vaccine knowledge," "vaccine attitudes/hesitancy," and "self-confidence" in immunization communication. The team assessing outcomes was unblinded to assignments. Hierarchical general linear model was used to adjust for residency type and residency year; residency site was modeled as a random effect.

Results: Overall, 1444 residents from 31 residency programs were eligible to participate (734 intervention, 710 control). The pre-intervention response rate was 730 (51%) and post-intervention was 526 (36%). Average knowledge scores increased from pre-intervention (control 53%; CoVER 53%) to post-intervention (control 58%; CoVER 60%). Increases in vaccine knowledge among FM residents were greater for CoVER compared to controls ($p = 0.041$). Vaccine hesitancy was more common among FM (23%) than Peds (10%) residents. In all three residency years, residents in the CoVER group showed greater increases in self-confidence in ability to discuss vaccines with parents/patients ($p < 0.03$) compared to control group.

Conclusion: The CoVER curriculum is an effective model to standardize immunization education of physicians-in-training. This RCT demonstrated the effectiveness of the CoVER curriculum to improve resident confidence in their ability to discuss vaccines with parents and patients.

1. Introduction

For individuals born in the U.S. from 1994 to 2013, vaccination will avert approximately 322 million illnesses, 21 million hospitalizations, and 732,000 deaths [1]. Despite these benefits, U.S. childhood and adult vaccination rates remain below *Healthy People 2020* goals [2,3]. One reason for lower vaccination rates is vaccine hesitancy. In response to the impact of vaccine hesitancy on population health, in 2019 the World Health Organization (WHO) included vaccine hesitancy as a top ten threat to public health. Few evidence-based strategies have been identified as effective pathways to decrease hesitancy, but parents, patients, and providers consistently report that strong provider vaccine recommendations increase vaccine confidence and compliance [4–6].

As the principal source of vaccine recommendations, primary care providers need in-depth knowledge and communication skills to optimally recommend vaccinations, answer common questions, and discuss the benefits and risks of vaccines with their patients. Although vaccine knowledge and communication skills ideally should be acquired during training, immunization education for

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providers-in-training is not standardized and is less than ideal [7]. A 2014 survey conducted by the Association of Pediatric Program Directors members showed that most pediatric training programs lacked a formal curriculum on vaccine safety or addressing vaccine hesitancy, yet most program directors believed such training would be valuable and important [8]. Another survey found that recent medical graduates were more skeptical of immunizations as compared to their older counterparts [9]. Such skepticism could increase the physician's willingness to delay or forego vaccination rather than attempt to persuade parents or patients to embrace this critical preventive health measure. The need to strengthen provider recommendations and better understand vaccine hesitancy among physicians-in-training and health care providers (HCPs) is critical to address vaccine hesitancy.

To bridge the educational gap found in the literature, the Collaboration for Vaccine Education and Research (CoVER) was created in 2016 with subject matter experts from pediatrics (Peds), family medicine (FM), pediatric infectious disease, vaccinology, and medical education. The CoVER team designed and developed a 1-year vaccine education curriculum to (A) augment Peds and FM residents' knowledge of and confidence in immunizations and (B) improve their competence and confidence in communicating with patients and families about vaccinations. The CoVER team also sought input from key stakeholders (e.g., residency program directors, education specialists, residents, Peds and FM leaders) regarding the curriculum format and content [10]. The resulting CoVER curriculum consisted of four interactive online modules that were developed with the application of best practices in instructional design to increase learners' engagement with a flexible and accessible format [11]. Further, the CoVER curriculum was designed to be easy to use and edit, allowing for the addition of up-to-date recommendations and information as vaccine recommendations constantly evolve. The CoVER curriculum can be accessed here: https://learningce.shea-online.org/content/collaboration-vaccine-education-and-research#group-tabs-node-course-default3.1.

We implemented the CoVER curriculum in Peds and FM residency programs across the U.S. and evaluated its impact through a randomized controlled trial (RCT) described here. The objective of this study was to evaluate the effectiveness of the CoVER curriculum with respect to three goals for educational improvement: 1) vaccine knowledge, 2) beliefs in the value of vaccination, and 3) confidence in discussing vaccination with parents and patients.

2. Methods

This RCT of an educational intervention for residents was conducted using a convenience sample of U.S. residency programs. Participating residency programs were randomly assigned using a 1:1 stratified sampling scheme to the intervention group (implement the CoVER curriculum in addition to their usual immunization training methods) or control group (continue their usual immunization training methods). The study was approved by the Children's Mercy Pediatric Institutional Review Board (IRB) and each participating institution's IRB prior to the program enrollment.

2.1. Participants

In 2016, the CoVER investigators recruited a convenience sample of pediatric, family medicine, and medicine-pediatric residency programs from academic institutions. All residents at each participating institution were eligible to participate and received an e-mail explaining the study. Resident participation was voluntary. While the year of residency was not part of the exclusion criteria for participating in this study, for the analysis we report results only for residents who self-identified as PGY1-PGY3, but excluded PGY4 residents (PGY4s, chief residents) because the intervention was designed to be part of the usual three-year residency program. Survey responses also were excluded if the survey question regarding residency site was not answered because we could not determine if the resident was in the intervention or control group.

A CoVER "champion" was identified at each participating program to coordinate communication throughout the study.

2.2. Intervention: the CoVER curriculum

In preparation for the development of the CoVER curriculum, a needs assessment was conducted via REDCap (Research Electronic Data Capture) [12] to gauge residents' and residency program directors' perspectives on vaccine education, vaccine education topic needs, and preferred curriculum format [11]. In addition, a roundtable meeting was convened including key stakeholders such as residents, residency program directors, Peds and FM membership organizations, vaccinologists, liaison representatives from the Advisory Committee on Immunization Practice (ACIP), and provider education specialists from the Centers for Disease Control and Prevention (CDC) National Center for Immunization and Respiratory Diseases (NCIRD).

Based on the results from the needs assessment surveys and roundtable feedback, the CoVER team designed and developed a curriculum consisting of five components, i.e., four interactive online modules followed by one face-to-face training [10]. To fit with the Peds and FM resident training time constraints -- each module was designed to be asynchronous, brief (completed in less than one hour), and flexible (could be completed either within one sitting or intermittently). Modules were created using the Articulate™ (*Rise 360*, rise.articulate.com) suite of educational software and hosted in the Learning Management System (LMS) powered by Cornerstone (Cornerstone OnDemand, Inc - cornerstoneondemand.com). Module access to the LMS was granted to residents by Children's Mercy Kansas City during the implementation of the CoVER curriculum.

Periodically throughout the 2017–2018 academic year residents in programs randomized to the CoVER curriculum were emailed an electronic link to one of the four online modules. Modules focused on four broad topics related to both childhood and adult vaccinations: vaccine fundamentals (September 2017), vaccine preventable diseases (November 2017), vaccine safety (January 2018), and vaccine communication strategies (March 2018). Module completion was tracked through the Learning Management System. After all modules were delivered to the residents, instructions for the face-to-face training (Appendix 1) were sent to the CoVER champions (March 2018). Each site implemented the face-to-face training in a manner that best fit their educational schedules and structure. For example, some faculty facilitated the sessions with the residents by themselves, others delegated the training to a volunteer faculty member (e.g., faculty from continuity clinic), while others implemented the training during a scheduled didactic session.

2.3. Outcomes

Pre- and Post-Intervention Surveys. We collected data through a survey created by the CoVER team (Appendix 2) that included six questions related to demographics information and 24 questions related to measures of interest in vaccine education described below: vaccine knowledge, attitudes, and self-confidence in vaccine communication. We emailed the survey link to all residents in both intervention and control groups using REDCap before ("pre-intervention" sent July/August 2017) and after the intervention ("post-intervention" sent May 2018). The pre-

and post-intervention surveys were the same. Two email reminders were sent for both pre- and post-intervention surveys to increase response rates. Each resident was asked to create a unique identifying code to allow us to link their pre- and post-intervention survey results without personal identifiers (first two letters of mother's first name, followed by last four digits of the resident's social security number). No incentives were provided directly to residents for voluntary survey completion.

Three Sets of Measures. The CoVER team created 14 **"**vaccine knowledge" questions based on the content of the four modules. Responses to knowledge questions were either correct or incorrect. Seven "vaccine attitudes and hesitancy" questions were adapted from the Parent Attitudes about Childhood Vaccines (PACV) Survey [13,14]. These questions had varied response options, including 5-point Likert scales, 1–100 scales, and binary yes/no. One of these questions, "*Overall, how hesitant about childhood vaccines would you consider yourself to be?*" had a 5-point Likert scale response option. Because the authors believed that healthcare providers should have the utmost trust in vaccines, we analyzed respondents as "vaccine hesitant" if they indicated any level of discomfort with vaccines. That is, in addition to the 5-point Likert scale, we also coded responses to this question as binary (either "vaccine confident" if they chose "not at all hesitant" or "vaccine hesitant" if they chose any other response, i.e., "not too hesitant", "not sure", "somewhat hesitant", "very hesitant"). To measure "self-confidence" in resident immunization communication**,** three questions were adapted and modified from other sources [15]. Using a 1–100 scale, residents responded to the following questions:

1) "*Do you consider yourself a vaccine novice or expert?*"
2) "*How confident do you feel in your ability to discuss vaccines with a parent who would like to delay or withhold one or more vaccines for their child?*", and
3) "*How well prepared do you feel to answer parental concerns regarding vaccines?*"

2.4. Sample size

Prior to data collection we performed a cluster-randomized trial sample size determination, specifically looking for detectable differences in proportions. For this determination we assumed 80% power, an alpha of 0.05, a 1:1 allocation of sites (i.e., number of CoVER sites equals number of control sites), and an ICC of 0.04; the average cluster size was derived based on the total number of residents for each site willing to participate in the study. These results also helped guide the decision on the number of sites to be enrolled.

2.5. Randomization

We randomly assigned participating residency programs using a 1:1 stratified sampling scheme to either the intervention or control group. Specifically, prior to randomization, sites were first allocated to the appropriate stratum (i.e., Pediatric vs. Family Medicine). A stratified, simple random sample without replacement was performed using SAS 9.2, with a 50% sampling rate *within* stratum. This helped ensure an equal allocation of CoVER and control sites for both Pediatric and Family Medicine sites. To minimize potential contamination effects, if an institution had more than one residency type, randomization was based on the random assignment of the program with the largest number of residents. For example, one institution had 26 Peds residents and 22 FM residents; thus, they both followed the randomization of the Peds program. In this way all residents within an institution were assigned to the same study group.

2.6. Blinding

The residents, site leaders, and CoVER team assessing outcomes were aware of the site assignments to either the intervention or control group.

2.7. Statistical methods

In order to preserve the benefit of randomization, we analyzed the data using an intent-to-treat approach, irrespective of module completion. Thus, residents in programs randomized to CoVER were analyzed in the intervention group irrespective of the number of CoVER modules they completed. For use in a secondary analysis, we attempted to validate the intervention exposure by asking residents how many of the online CoVER modules they had completed. The primary outcomes were changes in "vaccine knowledge," "vaccine attitudes/hesitancy," and "self-confidence" in resident immunization communication. Resident self-confidence was modeled as a continuous outcome, with the mean score compared across intervention group (i.e., CoVER vs. control) as well as contrasting changes over time (i.e., pre- vs. post-intervention surveys). A difference-in-difference approach was used to compare changes over time for the CoVER group versus changes over time in the control group. A hierarchical general linear model was used to adjust for residency type and residency year; residency site was modeled as a random effect. The frequency distributions of vaccine hesitancy ("vaccine confident" vs. "vaccine hesitant") and vaccine knowledge (correct/incorrect) were compared between the two groups. Pearson's chi-square statistics are reported. After adjusting for residency type and residency year, hierarchical logit models, with a random effect for residency site, were run to examine the relationship between vaccine hesitancy and intervention group. All analyses were completed using Stata (StataCorp. 2015. *Stata Statistical Software: Release 14*. College Station, TX: StataCorp LP).

3. Results

3.1. Participant flow and recruitment

In 2016, the CoVER investigators recruited a convenience sample of 31 residency programs (15 Peds, 14 FM, 2 Med-Peds) from 26 academic institutions. Four academic institutions had more than one residency program; specifically, two had both Peds and FM programs and two had both Peds and Med-Peds programs.

Fifteen residency programs (8 Peds, 7 FM, 0 Med-Peds) were randomized to the intervention group (the CoVER curriculum) and 16 programs (7 Peds, 7 FM, 2 Med-Peds) to the control group. In total, 1444 residents participated (734 assigned to the intervention and 710 to control groups) (Fig. 1).

3.2. Baseline data (Demographics)

Table 1 shows the demographics of eligible residents who responded to the pre-intervention survey. Module completion for residents assigned to the CoVER group (n = 734) is displayed in Fig. 2.

3.3. Numbers analyzed

Resident response rates. Although surveys from PGY4 residents were not analyzed for this manuscript, we included all residents in the denominator of the response rate calculation because we did not know the number of PGY4 residents for each residency program. Thus, these calculations are conservative. Of all residents (n = 1444), 730 residents completed the pre-intervention survey

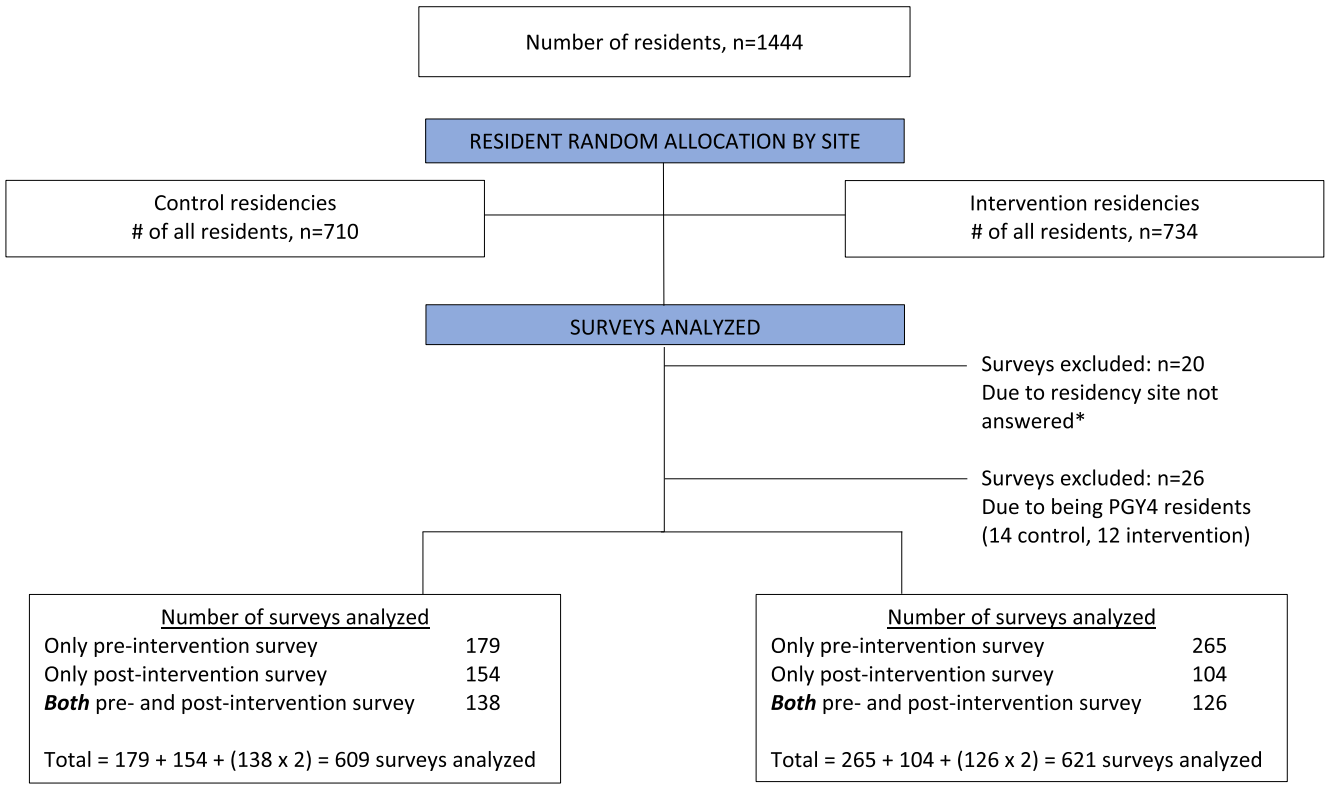

Fig. 1. Consort diagram. *If residency site question wasn't answered in the survey, we could not determine if resident was in the intervention or control group.

Table 1
Demographics of PGY1-PGY3 residents who completed the pre-intervention survey (N = 708*), by randomization group and overall.

		Control N = 317	CoVER N = 391	Overall (Control and CoVER) N = 708*	Pearson's Chi-Square
Resident Year					0.91
	Post-Graduate Year 1	116 (36.6%)	144 (36.8%)	260 (36.7%)	
	Post-Graduate Year 2	105 (33.1%)	124 (31.7%)	229 (32.3%)	
	Post-Graduate Year 3	96 (30.3%)	123 (31.5%)	219 (30.9%)	
Specialty					0.001
	Pediatrics	188 (59.3%)	241 (61.6%)	429 (60.6%)	
	Family Medicine	81 (25.6%)	125 (32.0%)	206 (29.1%)	
	Medicine-Pediatrics	33 (10.4%)	20 (5.1%)	53 (7.5%)	
	Other	15 (4.7%)	5 (1.3%)	20 (2.8%)	
Age (in Years)					0.292
	<30	227 (71.6%)	286 (73.1%)	513 (72.5%)	
	30–34	75 (23.7%)	83 (21.2%)	158 (22.3%)	
	35–39	11 (3.5%)	11 (2.8%)	22 (3.1%)	
	40 or more	3 (0.9%)	3 (0.8%)	6 (0.8%)	
	Prefer not to answer	1 (0.3%)	8 (2.0%)	9 (1.3%)	
Gender					0.259
	Male	92 (29.1%)	129 (33.1%)	221 (31.3%)	
	Female	224 (70.9%)	261 (66.9%)	485 (68.7%)	
Race/Ethnicity					0.124
	African American / Black	18 (5.7%)	11 (2.8%)	29 (4.1%)	
	Asian	63 (19.9%)	57 (14.6%)	120 (16.9%)	
	White	189 (59.6%)	262 (67.0%)	451 (63.7%)	
	Hispanic	16 (5.0%)	23 (5.9%)	39 (5.5%)	
	Other	7 (2.2%)	6 (1.5%)	13 (1.8%)	
	Unknown	24 (7.6%)	32 (8.2%)	56 (7.9%)	

*708 includes 444 residents that answered only the pre-intervention survey and 264 residents that answered both pre-intervention and post-intervention surveys.

for a response rate of 51% (730/1444); 54% (400/734) of residents in the intervention group and 46% (330/710) of residents in the control group completed pre-intervention surveys. The response rate was lower for the post-intervention survey (response rate of 36%, 526/1444); 32% (233/734) of residents in the intervention group and 41% (293/710) of residents in the control group completed post-intervention surveys.

Number of surveys analyzed. After excluding surveys from non PGY1-3 residents (n = 26) and surveys in which the residency site was omitted (n = 20), the resulting sample included 621 surveys

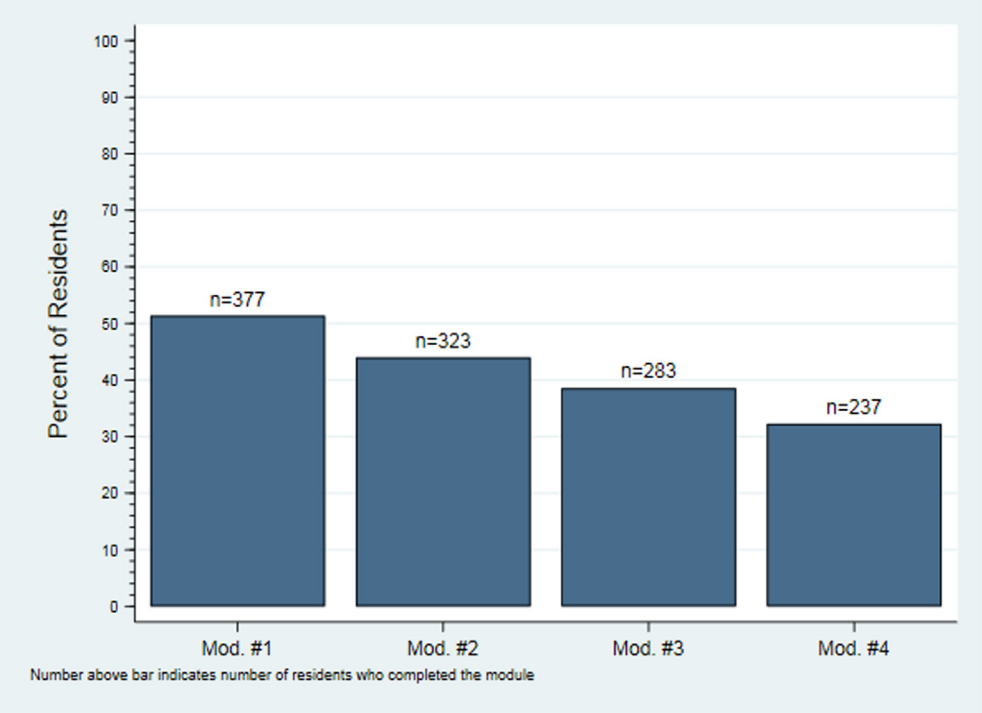

Fig. 2. Percentage of residents assigned to CoVER curriculum who completed each module.

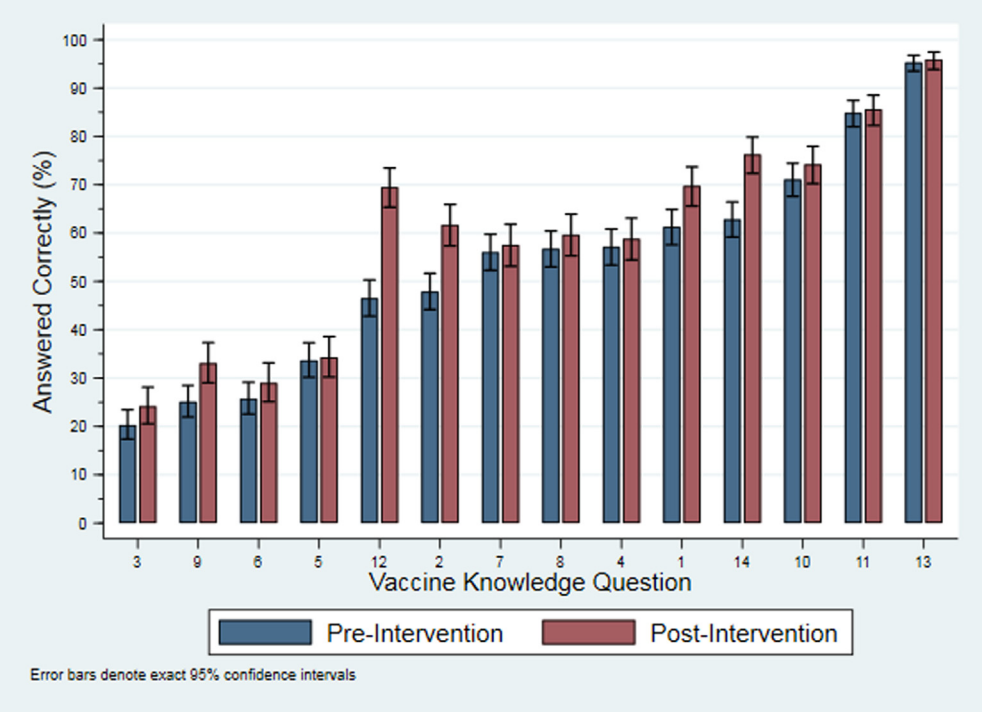

Fig. 3. Proportion of vaccine knowledge survey questions answered correctly, by time period.

for analysis in the intervention group and 609 surveys for analysis in the control group. Further, 444 residents answered *only* the pre-intervention survey (265 intervention, 179 control), 258 answered *only* the post-intervention (104 intervention, 154 control) and 264 answered both surveys (126 intervention, 138 control).

3.4. Outcomes

3.4.1. Outcome 1: vaccine knowledge

Vaccine knowledge questions created by the CoVER team ranged in difficulty (Fig. 3). Average knowledge scores (proportion of correct answers to vaccine knowledge questions) started low for

all residents; scores were 53% in both control and CoVER groups at baseline, demonstrating marked room for improvement. At the post-intervention period they were higher in both groups (control 58%; CoVER 60%; NS). Table 2 shows changes in vaccine knowledge for residents who completed both surveys (N = 264) based on specialty and residency.

By Specialty. Among residents who completed both surveys, it appears that, compared to FM residents, Peds residents had higher average knowledge scores both pre- and post-intervention in both control and CoVER groups. FM residents showed a non-significant decrease in knowledge in the control group from the pre-intervention (54%) to post-intervention (52%) period, and a significant increase in knowledge in the CoVER group from pre-intervention (49%) to post-intervention (57%). Increases in vaccine knowledge were significantly greater for CoVER FM residents compared to control FM residents (p = 0.041). FM residents in the intervention group started with a significantly lower knowledge score compared to the FM control group (49% vs 54%), but after the intervention, the intervention group knowledge score was higher than that of the control group (57% vs 52%).

By Residency Year. In general, baseline knowledge appeared higher, as expected, by year of training (PGY1s > PGY2s > PGY3s) and increased significantly over the course of the year for PGY1s in both the CoVER and control groups (p < 0.001). Knowledge increased in the CoVER group to a greater degree for PGY2s and PGY3s compared to the control group, but these differences did not reach statistical significance.

3.4.2. Outcome 2: vaccine attitudes and hesitancy

Overall, vaccine attitudes among residents were positive (Table 3). We categorized 14% of residents who completed the pre-intervention survey as "vaccine hesitant" in the binary analysis ("vaccine confident" if they chose "not at all hesitant" or "vaccine hesitant" if they chose any other response). Reported vaccine hesitancy was more common among FM residents (48/206; 23%) than Peds (42/427; 10%) or Med-Peds (4/53; 8%). (Note: 3/20 residents who were categorized as vaccine hesitant selected "other" for residency type). Among residents who completed both the pre- and post-intervention survey, 33 (13%) residents were categorized as "vaccine hesitant" in the pre-intervention survey. Twenty of these residents (61%) moved to the "confident" category in the post- survey; however, there was no difference between intervention and control groups.

3.4.3. Outcome 3: self-confidence in vaccine expertise and communication

From the pre-intervention to post-intervention period, resident self-reported vaccine expertise increased in both the control group (from 49% to 56%) and the intervention group (from 46% to 61%). The increase among the residents in the CoVER group was greater than the increase for residents in the control group (p < 0.001) (Table 4, see difference-in-difference result column to see change between groups). Similarly, self-confidence in the residents' ability to discuss vaccines with parents and to answer parents' vaccine questions improved to a greater degree in the CoVER group as compared to the control group.

Improvement in self-confidence was also seen among residents who completed both the pre- and post-intervention surveys (N = 264). The CoVER group residents in all three residency years showed significantly greater increases in self-confidence in their ability to discuss vaccines with parents (all p-values < 0.03) and in answering parents' vaccine questions (all p-values < 0.03) as compared to the control group residents. The increases in self-confidence for discussing vaccines was more pronounced among FM residents (21.3% CoVER vs. −0.9% control; difference-in-difference = 22.2%; p = 0.0009) than Peds residents (13.1% CoVER vs. 6.0% control: difference-in-difference = 7.1%; p = 0.066). A similar pattern was observed regarding confidence in answering vaccine questions.

4. Discussion

Educators and researchers agree, in order to address vaccine hesitancy, information alone will not translate into behavior change [16]. We designed a novel online vaccine education curriculum with the goal of improving not only vaccine knowledge, but residents' ability to respond to an epidemic of vaccine concerns with effective communication skills and confidence. Knowledge is a necessary first step for residents to understand the fundamentals of vaccines, but they also need to be confident in their ability to answer questions from patients. This aptitude is important because, although once common vaccine preventable diseases like measles are rarely encountered, these diseases can easily reemerge if we fail to address vaccine concerns adequately.

This RCT of a novel immunization education intervention for physicians-in-training has several important findings. At the end of the intervention residents in the CoVER group, as compared with residents in the control group, were more likely to report vaccine expertise, confidence in their ability to discuss vaccines with parents, and confidence in their ability to answer parents' questions. This improvement in self-confidence was encouraging because being comfortable addressing patients' vaccine questions is crucial to the communication skill that physicians should develop during residency. Additional support for this finding was found in a prior focus group study related to the CoVER curriculum, which highlighted that -- with improved confidence in vaccine communication from the CoVER modules -- some residents were able to transition previously resistant parents to vaccination acceptance [10].

In both the intervention and control groups at baseline, residents' attitudes toward vaccines and CDC vaccine information were positive. Among residents who responded to the baseline sur-

Table 2
Average vaccine knowledge score among residents that answered both pre-intervention and post-intervention surveys, by randomization group.

	Control				CoVER					
	Pre-	Post-	Change	p-value	Pre-	Post-	Change	p-value	Difference-in-Difference	p-value
By Resident Year										
PGY1	750 (49%)	753 (59%)	9.8%	<0.001	610 (48%)	615 (58%)	10.0%	<0.001	0.25%	0.947
PGY2	643 (56%)	643 (59%)	3.3%	0.236	642 (59%)	638 (65%)	6.2%	0.023	2.90%	0.452
PGY3	532 (62%)	532 (63%)	1.5%	0.613	503 (55%)	502 (62%)	6.9%	0.026	5.38%	0.210
By Specialty										
Pediatrics	1260 (56%)	1257 (63%)	7.0%	<0.001	1017 (57%)	1021 (65%)	8.1%	<0.001	1.12%	0.698
Family Medicine	387 (54%)	391 (52%)	−1.6%	0.660	710 (49%)	706 (57%)	7.5%	0.005	9.08%	0.041
Med-Peds	236 (50%)	238 (58%)	7.1%	0.118	28 (64%)	28 (61%)	−3.6%	0.782	−10.71%	0.435
Other**	42 (48%)	42 (57%)	8.7%	0.3002	–	–	–	–	–	–

Table 3
Resident attitudes and hesitancy.

	Pre-Intervention Survey (n = 708*)	Post-Intervention Survey (n = 522**)
Children get more vaccines than are good for them.		
Strongly agree – n (column %)	13 (1.8%)	16 (3.1%)
Agree	9 (1.3%)	6 (1.2%)
Not sure	18 (2.6%)	12 (2.3%)
Disagree	165 (23.4%)	92 (17.7%)
Strongly disagree	500 (70.9%)	394 (75.8%)
I believe that many of the illnesses vaccines prevent are severe.		
Strongly agree	556 (78.8%)	441 (85.1%)
Agree	138 (19.5%)	65 (12.5%)
Not sure	5 (0.7%)	5 (1.0%)
Disagree	3 (0.4%)	3 (0.6%)
Strongly disagree	4 (0.6%)	4 (0.8%)
It is better for my patient to develop immunity by getting sick than to get a vaccine.		
Strongly agree	8 (1.1%)	7 (1.3%)
Agree	6 (0.8%)	8 (1.5%)
Not sure	16 (2.3%)	10 (1.9%)
Disagree	201 (28.5%)	107 (20.6%)
Strongly disagree	475 (67.3%)	387 (74.6%)
I trust the information I receive about vaccines from the CDC.		
Strongly agree	557 (78.8%)	410 (79.2%)
Agree	139 (19.7%)	95 (18.3%)
Not sure	7 (1.0%)	7 (1.4%)
Disagree	0 (0.0%)	3 (0.6%)
Strongly disagree	4 (0.6%)	3 (0.6%)
Have you ever agreed to delay a vaccine in the absence of a true contraindication due to a patient or parental request?		
Yes	463 (65.9%)	392 (75.7%)
No	240 (34.1%)	126 (24.3%)
Overall, how hesitant about childhood vaccines would you consider yourself to be?		
Not at all hesitant	609 (86.3%)	452 (87.0%)
Not too hesitant	75 (10.6%)	55 (10.6%)
Not sure	8 (1.1%)	6 (1.2%)
Somewhat hesitant	14 (2.0%)	7 (1.4%)
How sure are you that following the recommended CDC vaccine schedule is a good idea for your patients? (range 0–100) – median [IQR]	97 [88, 100]	98 [89, 100]

*708 includes 444 residents that answered only the pre-intervention survey and 264 residents that answered both pre- and post-intervention surveys.
**522 includes 258 residents that answered only the post-intervention survey plus 264 residents that answered both pre- and post-intervention surveys.

Table 4
Self-confidence among residents (PGY1-PGY3) with known residency site, by randomization group, and who completed pre- and/or post-intervention surveys (N = 1,230).

	Control				CoVER					
	Pre-	Post-	Change	p-value	Pre-	Post-	Change	p-value	Difference-in-Difference	p-value
Perceived Expert Status (1: Novice; 100: Expert): Average score										
Do you consider yourself a vaccine novice or expert?	48.92	55.74	6.82	<0.001	45.88	61.22	15.34	<0.001	**8.52**	**<0.001**
Self-confidence (1: Low; 100: High): Average score										
How confidence do you feel in your ability to discuss vaccines with a parent who would like to delay or withhold one or more vaccines for their child?	56.33	63.57	7.24	<0.001	53.46	68.77	15.31	<0.001	**8.07**	**<0.001**
How well prepared do you feel to answer parental concerns regarding vaccines?	56.81	63.61	6.80	<0.001	54.68	69.05	14.38	<0.001	**7.58**	**<0.001**

vey, we found that 14% had some degree of reported vaccine hesitancy (“not too hesitant”, “not sure”, “somewhat hesitant”, or “very hesitant”), with FM residents more likely than Peds residents to have some degree of reported vaccine hesitancy. Our findings support other studies that found FM residents may need additional training in vaccine fundamentals, risks, and benefits in order to be optimally prepared [17,18]. Others have described vaccine hesitancy among medical students and health care workers in various

degrees, depending on the definition used [19]. Vaccine hesitancy is a major health threat and healthcare providers remain the most trusted advisors and influencers of vaccination decisions so this group should be confident regarding the safety, necessity, and importance of vaccines for their patients. Previous studies suggest that health care workers with a higher confidence in vaccinations are more willing to recommend vaccines to their patients [19].

Our study indicated that residents benefited from the CoVER comprehensive vaccine education program. The online component of CoVER could be extended to practitioners (e.g., physicians, nurse practitioners, physician assistants) in rural areas where known immunization disparities occur, such as lower HPV vaccination rates [20]. Family medicine physicians, who may derive special value from the CoVER curriculum, comprise only 15% of the U.S. outpatient physician workforce but provide 42% of the care in rural areas [21]. Importantly, immunization education for family medicine physicians may improve immunization coverage for adults as well as children. Since infectious diseases affect people during their entire lifespan, a great emphasis should be placed on adult vaccination. Some training on adult immunization is also useful for pediatricians who should be prepared to give vaccination advice to the entire family unit to keep everyone free of vaccine preventable diseases.

The CoVER curriculum was developed using best practices in instructional design with the goal of high user satisfaction, ease of use, and sustainability [22–25]. In focus groups with residents who had completed the CoVER curriculum, satisfaction with the curriculum was high and the interactive design and content were liked [10]. Other features of the CoVER curriculum that make it sustainable relate to the online platform allowing for easy updating as changes frequently arise (e.g., the new immunization schedule, evidence on best practices in vaccine delivery). Because the CoVER modules are accessible online, standardization of immunization education across the United States would be possible, even if face-to-face contact between teacher and learner is difficult (e.g., during pandemics). Further, in some settings these modules may help faculty refresh their own immunization knowledge. Previewing them would allow faculty immunization experts to do more in-depth teaching and role playing rather than being limited to traditional didactic teaching.

5. Study strengths and limitations

Our study has some limitations. We cannot generalize the knowledge and attitudes of residents in participating programs to all U.S. residency programs. Despite our large and diverse sample, residents were not required to complete the surveys, which limited our working sample size. Residents were not required to complete all the modules, which may have blunted their effect. Baseline characteristics may have been skewed if residents with more baseline knowledge or pro-vaccine attitudes were more likely to return surveys. The authors believed that healthcare providers should have the utmost trust in vaccines; thus, we classified respondents as "vaccine hesitant" if they indicated any level of discomfort with vaccines. Some residents did not enter their unique identifying code when completing their pre- and post-intervention surveys, thus hindering our ability to directly compare their pre- and post-intervention survey responses. Because randomization occurred at the program level and only two Med-Peds residency programs were involved, the distribution of Med-Peds residents was not equal in both groups. Residents' responses to survey questions regarding hesitancy and confidence were based on self-report. Even with these limitations, we still found important and impactful results associated with exposure to the CoVER curriculum.

6. Conclusion

Providers' vaccine recommendations are crucial to maintaining high levels of childhood immunization and improving levels of adult immunization [26–30]. Although increasing knowledge is a necessary first step, alone it is not sufficient to impact vaccination behavior. We developed a set of brief online immunization modules that were followed by an in-person session. The CoVER curriculum was constructed using best practices in adult education and designed to be easily disseminated online. The intervention had a notable positive effect on resident confidence in their ability to discuss vaccines and answer questions from patients. Our results suggest that knowledge about vaccine principles, efficacy, and safety helped residents build confidence in vaccine communication and may have augmented their willingness to recommend vaccines to patients.

Further studies need to be performed to determine if this change in attitudes and knowledge leads to better immunization rates. More work needs to be done to increase vaccine confidence during residency and, importantly, in medical schools so physicians in all specialties understand the value of vaccination as a foundational preventive measure. Immunization education is a vital component of preparation for those who will provide primary care for patients of any age in order to combat vaccine hesitancy.

Declaration of Competing Interest

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.vaccine.2020.09.043.

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