Foundational ECG Education for Physician Assistant Students: Outcomes of an Active Learning Intervention

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Abstract

ECG acquisition and cardiac electrophysiology are frequently undertaught in physician assistant cardiology curricula, with greater emphasis placed on pattern recognition than foundational ECG principles. This study examined whether a single active learning ECG session improved first-year PA students' knowledge and confidence in ECG acquisition and electrophysiology. Forty-two students participated in a 90-minute session; pre- and post-assessments revealed a 10.3 percentage point improvement in item-level performance, with the greatest gains in cardiac plane orientation and foundational recall. Student confidence in performing a 12-lead ECG increased substantially. These findings support integrating dedicated ECG acquisition instruction and hands-on skills training into PA cardiology curricula.

Introduction

Cardiology consistently represents one of the largest components of didactic education in Physician Assistant (PA) programs and accounts for a substantial portion of content on the PA national board examination.[1] Within cardiology, students must develop proficiency across a wide range of disease processes, pharmacology, and diagnostic modalities. Among these, electrocardiogram (ECG) interpretation stands out as a particularly essential and challenging skill. Accurate ECG interpretation is a competency that many experienced clinicians spend years refining, and it is an area in which students often struggle.[2] Given the clinical significance of this skill, where misinterpretation can directly alter a patient's diagnosis and treatment course, PA programs must regularly evaluate their curricula to ensure students are adequately prepared for both their clinical year and independent practice.[3]

Current ECG curricula across most health professions programs tend to emphasize pathological pattern recognition, training students to rapidly identify whether a tracing is normal or abnormal.[4,5,6] While this approach provides a useful foundation, an over-reliance on pattern recognition can create significant gaps in understanding. When a clinical presentation does not match the patterns learned in the classroom, providers may be left without the conceptual framework needed to reason through the tracing. Although electrophysiology is typically introduced during early cardiology lectures to explain the basis of the ECG waveform, it may not always serve as a sustained focus of instruction and is often treated as preliminary background rather than essential, applied knowledge.[7] Even less commonly addressed is the practical process of ECG acquisition, including how lead placement relates to cardiac electrical vectors and waveform morphology, which based on available literature and the authors' observations within one PA program, appears to receive limited dedicated curricular attention.[4,5,6] In some clinical settings, including rural and urgent care environments, advanced practice providers, including PAs, may be directly responsible for both acquiring and interpreting ECGs, making foundational knowledge of electrode placement essential to clinical practice.[8] Furthermore, clinicians will regularly encounter ECGs affected

by lead misplacement or technical artifact, which can closely mimic true pathology.[9] Recognizing these errors and understanding their origin requires the same foundational knowledge of how an ECG is acquired and how electrode position determines waveform appearance.

The existing literature demonstrates that supplemental ECG education generally improves student confidence and performance.[10,11,12] However, most published studies focus on medical students rather than PA students, and the majority address ECG interpretation broadly rather than the foundational concepts of lead placement and electrophysiologic reasoning that underpin accurate acquisition and interpretation.[13] This gap in the literature supports the need to evaluate targeted educational interventions that emphasize these foundational principles within the context of PA education. Therefore, this study evaluates the impact of an active, application-based ECG teaching session, focused on lead placement and cardiac electrophysiology, on first-year PA students' understanding of electrophysiologic concepts and their ability to accurately interpret ECGs. The primary aim was to determine whether this intervention produced a measurable improvement in students' knowledge and application of these concepts as assessed by pre- and posttest performance. Secondary aims included evaluating whether the session improved students' ability to recognize lead-placement errors and technical artifacts, increased their self-reported confidence in ECG interpretation, and was perceived as a valuable addition to the existing cardiology curriculum.

Methods

Study Setting and Participants

This study was conducted at the Northwestern University Physician Assistant Program. The study population consisted of 42 first-year PA students enrolled in the program. Participation in both the pre- and post-assessment surveys was voluntary; however, all students were required to participate in the educational component of the intervention, as it was incorporated into the first-year curriculum. All

survey responses were kept anonymous, and data were collected through Canvas, the program's learning management platform.

Pre-Assessment Survey

Approximately one week prior to the intervention, a pre-assessment survey was distributed to all students through Canvas. The survey consisted of 16 knowledge-based questions organized around four learning objectives: (1) ECG lead placement and acquisition, (2) cardiac planes and electrical orientation, (3) vectors and waveform interpretation, and (4) recognition of ECG errors, lead misplacement, and artifact. Each learning objective was assessed by four questions, with each question corresponding to a successive level of Bloom's Taxonomy: Remember, Understand, Apply, and Analyze. This structure was designed to evaluate students' depth of understanding across multiple cognitive levels for each content domain. The pre-assessment survey was closed the evening before the intervention took place.

In addition to the 16 knowledge-based questions, four supplementary questions were included in the pre-assessment to characterize students' prior exposure and confidence in regard to ECG acquisition, error and artifact, and other related topics. These questions were intended to assess whether students had previous experience with ECG lead placement or acquisition prior to the intervention, providing context for interpreting pre-assessment performance.

Intervention

The educational intervention consisted of a 90-minute active, application-based lecture focused on ECG lead acquisition, cardiac electrophysiology, and the identification of common acquisition errors and artifacts. At the beginning of the session, students were provided with a standardized 12-lead ECG anatomical diagram handout and asked to identify and mark the correct placement of all ECG leads on the diagram. Students were asked to complete two components for each electrode: identify the correct anatomical landmark by name, including the specific intercostal space and border or line, and mark the

corresponding position on the provided anatomical diagram. Students were not instructed to review lead placement prior to the session; this activity was intentionally designed to assess their baseline practical knowledge before any formal instruction was delivered.

The lecture content that followed included instruction on how to correctly perform a 12-lead ECG, how each electrode corresponds to the leads seen on a standard tracing, how electrode position relates to cardiac electrical vectors and waveform morphology, and how lead misplacement and technical artifacts produce predictable and recognizable changes in the ECG. The session was structured to reinforce foundational electrophysiologic reasoning as the basis for both accurate ECG interpretation and recognition of acquisition-related errors.

Post-Assessment Survey

Immediately following the conclusion of the lecture, students were asked to complete a post-assessment survey, also administered through Canvas. The post-assessment included 16 knowledge-based questions that were parallel in structure and content to the pre-assessment, using equivalent questions designed to assess the same four learning objectives across the same four levels of Bloom's Taxonomy. Parallel rather than identical questions were used to minimize recall bias while maintaining content comparability between assessments. The post-assessment survey opened immediately following the lecture and remained open for one week before being closed for data review.

In addition to the 16 knowledge-based questions, the post-assessment included a series of qualitative and perceptual items. These questions asked students to reflect on their experience with the intervention, share their perceptions of the session's educational value and relevance, provide feedback on the existing ECG curriculum, and indicate whether they would have found it beneficial to perform a 12-lead ECG on themselves as part of the learning experience.

Statistical Analysis

Quantitative data were analyzed using descriptive statistics, including means, standard deviations, and frequency distributions, to characterize pre- and post-assessment performance at the overall, domain, and Bloom's taxonomy cognitive level. Two performance metrics were calculated and reported. The Canvas-calculated mean student score, reflecting the average of individual student total scores, was used for overall quiz-level pre- and post-assessment comparison. The mean item-level difficulty, defined as the average proportion of students answering each question correctly across all 16 items, was used for domain-level analysis, Bloom's taxonomy level comparisons, and effect size calculations. These two metrics differ in their calculation methodology and are reported separately throughout the results.

Because pre- and post-assessment data were collected anonymously through the Canvas learning management system, individual student scores could not be linked across time points. As a result, matched-pairs statistical testing, including the paired t-test, Wilcoxon signed-rank test, and McNemar test, was not feasible. Instead, effect sizes for item-level pre- to post-assessment change were calculated using Cohen's h, the appropriate effect size statistic for comparing two independent proportions. Cohen's h is calculated as $h = 2 \cdot \arcsin(\sqrt{p_2}) - 2 \cdot \arcsin(\sqrt{p_1})$, where p_1 and p_2 represent the pre- and post-assessment proportions of correct responses for a given item, respectively.[14] Effect sizes were interpreted using conventional thresholds: negligible ($h < 0.20$), small (0.20 – 0.49), medium (0.50 – 0.79), and large ($h \geq 0.80$).[14] Cohen's h values were calculated for each of the 16 parallel item pairs and subsequently averaged within each content domain and Bloom's taxonomy level to characterize overall patterns of change.

For the in-class electrode labeling activity, performance was summarized using frequency counts and percentage correct, calculated separately for the anatomy and diagram scoring categories and for limb versus precordial electrode groupings. For the anatomy category, a response was scored as correct only if the student identified both the precise intercostal space and the correct border or line for that electrode. For the diagram category, a response was scored as correct if the electrode was placed in the anatomically correct position and correctly labeled on the diagram.

Confidence data from Likert-scale items on both the pre- and post-assessment were summarized using frequency distributions and percentage of respondents within each response category. For two items with sufficiently parallel wording across pre- and post-assessment administrations, shift in the combined proportion of moderately or very confident respondents was reported descriptively as a percentage point change. Because the confidence questions used a rating scale and individual student responses could not be matched between the pre- and post-assessment, formal statistical testing was not performed on these items. Post-assessment perception questions, which used a agree-to-disagree response scale, were summarized by reporting the percentage of students who selected agree or strongly agree for each item.

Qualitative data from two open-ended post-assessment items were analyzed using thematic analysis to identify recurring patterns in student responses. Responses were reviewed independently, recurring themes were identified and labeled, and frequency counts were recorded for each theme to provide descriptive context. Thematic analysis was conducted by a single reviewer.

Results

Participants

Participants in this study were first-year physician assistant students enrolled in the Northwestern University PA Program. Both pre- and post-assessment surveys were made available to all 42 enrolled students. Survey participation was voluntary, though students were strongly encouraged to complete both assessments via multiple email reminders. No academic penalty was associated with non-completion. All 42 students were required to participate in the intervention lecture and associated in-class activity regardless of survey participation. Of the 42 enrolled students, 39 completed the pre-assessment survey, yielding a response rate of 93%. Of those 39 students, 24 also completed the post-assessment survey, representing a post-assessment response rate of 62%. The decline in response rate from pre- to post-assessment is attributed to the voluntary nature of the surveys and is addressed further in the Limitations section. Of the 39 pre-assessment responses, 41% (n=16) reported never having performed a

12-lead ECG. Among those with prior experience, 10% reported performing 1–5 ECGs, 10% reported performing 6–15 ECGs, and 38% reported performing more than 15 ECGs, indicating a bimodal distribution of prior experience within the cohort.

In-Class Activity: Baseline Practical Knowledge

Prior to receiving any instruction, students completed an in-class activity designed to assess baseline practical knowledge of ECG electrode placement. Thirty-six of the 42 students present completed the activity; the remaining six either were absent or elected not to participate.

For the electrode labeling portion, students were asked to identify the correct anatomical placement of all ten electrodes required for a standard 12-lead ECG and to mark their positions on an anatomical diagram. Performance was scored across two categories: anatomy (correctly naming the precise anatomical landmark, including intercostal space and border or line) and diagram placement (correctly marking and labeling each electrode on the anatomical diagram). Students achieved a correct response rate of 33% for the anatomy category and 29% for the diagram category, yielding an overall combined correct response rate of 31% (mean score 6.2 out of 20 points). Students demonstrated notably higher accuracy for limb electrode placement compared to precordial electrode placement, with combined correct response rates of 40% and 24%, respectively (Table 1).

Electrode Labeling Activity (20 points possible: 10 Anatomy + 10 Diagram)						
Electrode	Anatomy Score (1 pt each)		Diagram Score (1 pt each)		Combined	
	n Correct	% Correct	n Correct	% Correct	Anatomy + Diagram %	Electrode Mastery
RA (Right Arm)	15	42%	16	44%	43%	**Limited**
LA (Left Arm)	15	42%	16	44%	43%	**Limited**
RL (Right Leg)	13	36%	14	39%	38%	**Limited**
LL (Left Leg)	13	36%	14	39%	38%	**Limited**
V1 (4th ICS R sternal)	14	39%	5	14%	26%	**Poor**
V2 (4th ICS L sternal)	14	39%	5	14%	26%	**Poor**

V3 (between V2 & V4)	9	25%	6	17%	21%	**Poor**
V4 (5th ICS midclav)	11	31%	9	25%	28%	**Poor**
V5 (ant axillary line)	7	19%	9	25%	22%	**Poor**
V6 (mid axillary line)	8	22%	10	28%	25%	**Poor**
Limb Electrode Average		**39%**		**42%**	**40%**	**Moderate**
Precordial Electrode Average		**29%**		**20%**	**24%**	**Poor**
Overall Average (all electrodes)		**33% (3.3/10)**		**29% (2.9/10)**	**31% (6.2/20)**	**Poor**

Scoring: Anatomy (1 pt) = correct intercostal space AND correct border/line named. Diagram (1 pt) = electrode placed in correct position on anatomical diagram AND correctly labeled. Green ≥ 60%, Yellow 35–59%, Orange < 35%.

Table 1: In-Class Electrode Labeling Results: correct response rates by electrode, grouped limb vs precordial

Note on Performance Metrics

Two performance metrics are reported throughout this results section. The Canvas-calculated mean student score reflects the average of individual student total scores and is used for overall quiz-level comparisons between pre- and post-assessment. The mean item-level difficulty is calculated as the average proportion of students answering each question correctly across all 16 items and is used for domain-level analysis, Bloom's taxonomy comparisons, and effect size calculations. These metrics differ in their calculation methodology and are not directly interchangeable. The implications of the observed discrepancy between these two metrics are discussed further in the Limitations section.

Pre-Assessment Knowledge Findings

The Canvas-reported mean student score on the pre-assessment was 62% (SD = 11.7%, range 40–81%). The mean item-level difficulty across all 16 pre-assessment questions was 70.9% (SD = 20.8%, range 38–97%). The wide standard deviation reflects substantial variability across content areas, with some concepts near mastery and others near chance-level performance.

The highest pre-assessment item-level performance was observed on the question identifying the anatomical placement of V1 and V2 (97% correct), with several additional items exceeding 90% correct, including questions addressing cardiac plane assessment, electrode requirements, QRS polarity, and ventricular depolarization direction. The weakest pre-assessment performance was observed on questions addressing cardiac plane orientation, axis direction, electrode reversal effects, and precordial lead misplacement, with correct response rates ranging from 38% to 51% on these items. This pattern suggests that students entered the session with a stronger command of conceptual and recall-level knowledge than applied and analytical reasoning (Table 2).

Pre- vs Post-Assessment Analysis

Pre-assessment n = 39 | Post-assessment n = 24

Question Information					Pre-Assessment			Post-Assessment			Effect			Std Dev	
#	Domain	Bloom's Level	Pre-Assessment Question (summary)	Post-Assessment Question (summary)	Correct n	Total n	Pre %	Correct n	Total n	Post %	Δ %	Cohen's h	Effect Size	Pre SD	Post SD
1	Lead Placement	Remember	V1/V2 anatomical placement	V4 anatomical placement	38	39	97%	19	24	79%	**-18%**	**-0.626**	Medium	0.156	0.406
2	Lead Placement	Understand	First landmark for precordial leads	First step for precordial leads	23	39	59%	19	24	79%	**+20%**	**0.442**	Small	0.494	0.406
3	Lead Placement	Apply	Effect of incorrect precordial placement	Precordial leads too lateral: effect	20	39	51%	15	24	63%	**+11%**	**0.227**	Small	0.5	0.484
4	Lead Placement	Analyze	Why both limb & precordial required	Only limb leads misses anterior ischemia	35	39	90%	20	24	83%	**-6%**	**-0.189**	Negligible	0.303	0.373
5	Planes & Orientation	Remember	Which leads record frontal plane	Which leads record horizontal plane	26	39	67%	23	24	96%	**+29%**	**0.820**	Large	0.477	0.2
6	Planes & Orientation	Understand	Meaning of leads viewing heart from 'planes'	What do different 'views' describe	36	39	92%	23	24	96%	**+4%**	**0.151**	Negligible	0.266	0.2
7	Planes & Orientation	Apply	Which plane assesses anterior anatomy	Which leads give anterior view of the heart	15	39	38%	20	24	83%	**+45%**	**0.963**	Large	0.487	0.373
8	Planes & Orientation	Analyze	Why one plane is insufficient	Why frontal vs horizontal waveforms differ	37	39	95%	24	24	100%	**+5%**	**0.457**	Small	0.221	0

9	Vectors & Waveform	Remember	Mean direction of ventricular depolarization	Mean direction of ventricular depolarization	27	39	69%	22	24	92%	**+22%**	**0.590**	Medium	0.462	0.276
10	Vectors & Waveform	Understand	Why QRS positive lead I, negative aVR	What explains upright QRS in lead I	35	39	90%	21	24	88%	**-2%**	**-0.071**	Negligible	0.303	0.331
11	Vectors & Waveform	Apply	QRS when vector moves toward electrode	Upright QRS complex and direction of ventricular depolarization	35	39	90%	22	24	92%	**+2%**	**0.066**	Negligible	0.303	0.276
12	Vectors & Waveform	Analyze	Axis: QRS positive lead I, negative aVF	Axis: QRS positive aVF, negative lead I	19	38	50%	17	24	71%	**+21%**	**0.430**	Small	0.5	0.455
13	Errors & Artifact	Remember	RA–LA reversal alters which lead	Which error most directly alters lead I	19	39	49%	22	24	92%	**+43%**	**1.011**	Large	0.5	0.276
14	Errors & Artifact	Understand	Why artifact must be recognized first	Feature suggesting interpret cautiously	34	39	87%	18	24	75%	**-12%**	**-0.315**	Small	0.334	0.433
15	Errors & Artifact	Apply	V1/V2 too high: how ECG changes	Finding suggesting V1/V2 misplacement	16	39	41%	13	24	54%	**+13%**	**0.264**	Small	0.492	0.498
16	Errors & Artifact	Analyze	All precordial leads inverted explanation	Precordial inverted, limb normal: why	27	39	69%	14	24	58%	**-11%**	**-0.227**	Small	0.462	0.493

Table 2: Item-Level Pre- and Post-Assessment Performance for All 16 Questions Including Domain, Bloom's Taxonomy Level, Correct Response Rates, Score Change, and Cohen's h Effect Size

At the domain level, the highest pre-assessment performance was observed in the Vectors and Waveform domain (75% correct), followed by Lead Placement (74%), Planes and Orientation (73%), and Errors and Artifact (62%). At the Bloom's taxonomy level, Understand-level questions demonstrated the highest pre-assessment performance (82% correct), while Apply-level questions demonstrated the lowest (55% correct).

Pre-assessment confidence data indicated that 93% of students rated themselves as not confident at all or only slightly confident in their ability to distinguish true cardiac pathology from technical error or artifact, with no student reporting very high confidence in this area. Regarding electrode placement, 49% of students reported being not confident or only slightly confident. In contrast, 64% of students reported feeling moderately or very confident in their understanding of how an ECG is used to assess cardiac electrical activity (Table 3).

Confidence & Perceptual Data — Pre- vs Post-Assessment Comparison										
Confidence Questions with Pre & Post Equivalents (4-point scale: Not Confident at All → Very Confident)										
Question	Pre-Assessment (n=39)				Post-Assessment (n= 25)				Shift	
	Not Conf. at all	Slightly Conf.	Moderately Conf.	Very Conf.	Not Conf. at all	Slightly Conf.	Moderately Conf.	Very Conf.	Mod + Very Pre → Post	Direction
Distinguishing true cardiac pathology from technical error/artifact PRE Q19 | POST: near-identical wording	49% (n=19)	44% (n=17)	13% (n=5)	0% (n=0)	8% (n=2)	52% (n=13)	36% (n=9)	4% (n=1)	**13% → 40% (+27pp)**	**▲ Improved**
Confidence with ECG electrode placement / performance PRE Q18: confidence correctly placing all electrodes POST: confidence independently performing 12-lead ECG	31% (n=12)	18% (n=7)	26% (n=10)	28% (n=11)	0% (n=0)	16% (n=4)	40% (n=10)	44% (n=11)	**54% → 84% (+30pp)**	**▲ Improved**
Understanding how ECG assesses cardiac activity PRE Q20: confidence rating (4-point scale) POST: rephrased as agree/disagree — not directly comparable → Reported descriptively in Table 6	8% (n=3)	28% (n=11)	49% (n=19)	15% (n=6)	—	—	—	—	**No direct post match**	See Table 6

Table 3: Pre- and Post-Assessment Confidence Ratings for Comparable Items: Response Distributions Across a 4-Point Scale (Not Confident at All to Very Confident)

Post-Assessment Knowledge Findings and Pre–Post Comparison

The Canvas-reported mean student score on the post-assessment was 62% (SD = 14.7%, range 40–77%), unchanged from the pre-assessment mean. The mean item-level difficulty across all 16 post-assessment questions was 81.2% (SD = 13.9%, range 54–100%), representing a 10.3 percentage point improvement over the pre-assessment item-level mean of 70.9%. The discrepancy between the unchanged Canvas mean and the item-level improvement is believed to reflect the influence of administration timing on post-assessment engagement, as students completed the post-assessment immediately following the lecture session before receiving a break. This is addressed further in the Limitations section. The decrease in item-level standard deviation from 20.8% to 13.9% indicates that student performance became more consistent across items following the intervention, suggesting that the session disproportionately improved performance on previously lower-scoring questions and reduced knowledge variability across the cohort.

Of the 16 parallel post-assessment items, students demonstrated improvement on 11 and declined on 5. The four questions showing the greatest individual improvement included the following. Question 13, which assessed recognition of the ECG lead most directly affected by right arm-left arm electrode reversal, improved from 49% to 92% correct (Cohen's h = 1.011, large effect). Question 7, which assessed application of knowledge regarding which cardiac plane evaluates anterior anatomy, improved from 38% to 83% correct (h = 0.963, large effect). Question 5, which assessed recall of which ECG leads record frontal versus horizontal plane electrical activity, improved from 67% to 96% correct (h = 0.820, large effect). Question 9, which assessed recall of the mean direction of ventricular depolarization, improved from 69% to 92% correct (h = 0.590, medium effect). Three questions demonstrated notable declines. Question 1, which assessed recall of V1 and V2 anatomical placement on the pre-assessment, declined from 97% to 79% correct (h = −0.626, medium effect). This decline is most likely attributable to a parallel-form effect, as the post-assessment counterpart assessed V4 placement rather than V1 and V2, representing a meaningfully different and less frequently reinforced landmark. Question 14, which

assessed understanding of why artifact must be identified before rhythm interpretation, declined from 87% to 75% correct (h = −0.315, small effect). Question 16, which assessed analysis of a scenario in which all precordial leads appeared inverted while limb leads remained normal, declined from 69% to 58% correct (h = −0.227, small effect). Full item-level results for all 16 question pairs are presented in Table 2.

Domain-Level Analysis

At the domain level, the greatest overall improvement was observed in the Planes and Orientation domain, which increased from 73% to 94% correct, yielding an average Cohen's h of 0.598 (medium effect). The Vectors and Waveform domain demonstrated a moderate improvement from 75% to 85% correct (average h = 0.254, small effect). The Errors and Artifact domain showed a modest improvement from 62% to 70% correct (average h = 0.183, negligible effect), though this overall figure obscures notable variation within the domain: the Remember-level item showed a large individual gain while higher-order items within the same domain declined. The Lead Placement domain demonstrated minimal overall change, improving from 74% to 76% correct (average h = −0.036, negligible effect), a result substantially influenced by the parallel-form framing shift on Question 1 as described above (Table 4).

Domain Summary									
Domain	**Pre Avg**	**Post Avg**	**Δ**	**Remember Δ**	**Understand Δ**	**Apply Δ**	**Analyze Δ**	**Avg Cohen's h**	**Effect Size**
Lead Placement	74%	76%	**2%**	**-18%**	**+20%**	**+11%**	**-6%**	-0.036	Negligible
Planes & Orientation	73%	94%	**21%**	**+29%**	**+4%**	**+45%**	**+5%**	0.598	Medium
Vectors & Waveform	75%	85%	**11%**	**+22%**	**-2%**	**+2%**	**+21%**	0.254	Small
Errors & Artifact	62%	70%	**8%**	**+43%**	**-12%**	**+13%**	**-11%**	0.183	Negligible
Overall Average	**71%**	**81%**	**10%**					**0.250**	**Small**

Table 4: Pre- and Post-Assessment Item-Level Performance by Domain

Bloom's Taxonomy Level Analysis

When performance was aggregated across all domains by Bloom's taxonomy level, Remember-level questions demonstrated the greatest improvement, increasing from 71% to 90% correct (average h = 0.449, small effect). Apply-level questions showed a similarly strong improvement, increasing from 55% to 73% correct (average h = 0.380, small effect). In contrast, Understand-level questions showed minimal change, increasing from 82% to 84% correct (average h = 0.052, negligible effect), as did Analyze-level questions, which increased from 76% to 78% correct (average h = 0.118, negligible effect). The pattern of greater gains at the Remember and Apply levels, relative to Understand and Analyze levels, is consistent with an intervention focused on foundational knowledge acquisition and practical application (Table 5).

Performance by Bloom's Taxonomy Level (all domains pooled)					
Bloom's Level	Pre Avg	Post Avg	Δ	Avg Cohen's h	Effect Size
Remember	71%	90%	**19%**	0.449	Small
Understand	82%	84%	**2%**	0.052	Negligible
Apply	55%	73%	**18%**	0.380	Small
Analyze	76%	78%	**2%**	0.118	Negligible

Table 5: Pre- and Post-Assessment Performance by Bloom's Taxonomy Cognitive Level Across All Domains

Post-Assessment Confidence and Perceptual Findings

Post-assessment confidence data were compared to pre-assessment responses on two parallel items. Regarding confidence in distinguishing true cardiac pathology from technical error or artifact, the proportion of students reporting moderate or high confidence increased from 13% pre-intervention to 40% post-intervention, a shift of 27 percentage points. Despite this improvement, 60% of students continued to rate their confidence as not confident at all or only slightly confident post-intervention, indicating that artifact recognition remains an area of limited confidence. Regarding confidence in electrode placement

and ECG performance, the proportion of students reporting moderate or high confidence increased from 54% pre-intervention to 84% post-intervention, a shift of 30 percentage points.

Prior to the intervention, 64% of students reported moderate or high confidence in their understanding of how an ECG is used to assess cardiac electrical activity. Following the session, 84% of students agreed or strongly agreed that the session improved their understanding of the relationship between electrophysiology and ECG waveforms. Due to differences in response scale between these two items, this comparison is reported descriptively only.

Three additional post-assessment items assessed student perceptions of the session with no pre-assessment equivalents. Ninety-six percent of students agreed or strongly agreed that the in-class electrode labeling activity helped them recognize gaps in their baseline understanding of ECG acquisition. Ninety-six percent agreed or strongly agreed that participating in hands-on ECG electrode placement on a person would have improved their understanding of the material. 84% agreed or strongly agreed that the session improved their understanding of the relationship between electrophysiology and ECG waveforms (Table 6).

Post-Assessment Perceptual Items (4-point scale: Strongly Disagree → Strongly Agree) | All 24/24 completed										
Post-Assessment Item	**Disagree**		**Agree**							
	Strongly Disagree	**Disagree**	**Agree**	**Strongly Agree**	**n**	**Combined Agree %**	**Pre Context / Notes**			
This session improved my understanding of the relationship between electrophysiology and ECG waveforms	4% (n=1)	12% (n=3)	76% (n=19)	8% (n=2)	n=25	**84%**	*PRE Q20: 64% moderately/very confident in ECG understanding (different scale — descriptive only)*			
Labeling the ECG helped me recognize gaps in my baseline understanding of ECG acquisition	0% (n=0)	4% (n=1)	62% (n=15)	33% (n=8)	n=24	**96%**	*Supported by in-class activity: mean electrode labeling score = 31% (6.2/20) before instruction*			
Participating in hands-on ECG electrode placement would have improved my understanding of the material	0% (n=0)	4% (n=1)	20% (n=5)	76% (n=19)	n=25	**96%**	*PRE: 41% had never performed an ECG; 38% had performed >15 (bimodal experience distribution)*			

Table 6: Post-Assessment Perceptual Item Response Distributions Across a 4-Point Scale (Strongly Disagree to Strongly Agree)

Qualitative Findings

Two open-response questions were included in the post-assessment. The first asked students when they would want the opportunity to perform a hands-on ECG. Thematic analysis of 20 responses identified three primary themes. The most frequently cited preference, reported by 13 respondents, was to receive ECG training during the cardiology unit. A second theme, identified by 5 respondents, was integration into existing skills laboratory sessions, with students suggesting the session be structured similarly to current point-of-care ultrasound sessions in which small groups rotate through clinical skills stations. A third theme, cited by 4 respondents, was the desire to complete hands-on ECG training prior to or during clinical year preparation.

The second open-response question solicited general feedback on the session. The majority of students responded positively, with many acknowledging gaps in their prior understanding of ECG electrophysiology and electrode placement that had not been addressed in the existing cardiology curriculum. One student offered the following representative response:

> *I think a lot of ECG lectures in our cardio unit focused on identifying different rhythms, pathologies, etc., but we didn't go in great depth of the actual act of placing ECG electrodes and identifying the proper steps in this level of detail. I think it [is] much different to just read about something or think you know something, but when forced to actually draw out where the electrodes go, it forces you to take it a step further and identify your gaps in knowledge.*

Constructive feedback centered on three recurring themes: a desire for more practice ECGs with applied interpretation exercises, greater emphasis on differentiating artifact from true pathology with specific clinical examples, and inclusion of more clinical correlates such as ST-elevation myocardial infarction patterns relevant to clinical year preparation. Two students also requested access to the presentation slides, suggesting the material was perceived as a valuable ongoing reference resource.

Discussion

This study examined whether a single active, application-based ECG teaching session improved first-year physician assistant students' knowledge of cardiac electrophysiology and ECG acquisition. While first-year PA students at Northwestern receive a four-week cardiology course, exposure to ECG acquisition within that curriculum is limited and no hands-on training is provided. This study was designed to determine whether a targeted supplemental session addressing this gap produced measurable knowledge gains and to explore student perceptions of the intervention in order to inform future curriculum development.

Primary Knowledge Findings

The primary finding of this study was that the intervention produced meaningful improvement in students' knowledge of ECG electrophysiology and acquisition across all four content domains. At the item level, the mean proportion of correct responses increased by 10.3 percentage points from 70.9% to 81.2%, with 11 of the 16 parallel question pairs demonstrating improvement. The overall average Cohen's h of 0.250 indicates a small effect size; however, small effect sizes remain educationally meaningful in the context of a single supplemental session, particularly when individual items demonstrated large effects.[15]

The three questions demonstrating the largest individual gains warrant specific attention. Two originated from the Planes and Orientation domain, reflecting improved student understanding of which cardiac planes and ECG views are used to assess different regions of cardiac anatomy. The third high-gain question addressed right arm-left arm electrode reversal within the Errors and Artifact domain, a clinically relevant acquisition error that students reported limited prior exposure to within the standard cardiology curriculum. The fact that focusing on even one specific artifact type in depth appears to have been effective in improving recognition of that error suggests that targeted case-based instruction on additional artifact types could yield similar gains.

It is important to address the absence of improvement in the Canvas-reported mean student score, which remained at 62% from pre- to post-assessment. The most likely explanation for this discrepancy is the timing of post-assessment administration. Students were asked to complete the post-assessment immediately following the 90-minute lecture session, before receiving a scheduled break, and with another session to follow. This likely led many students to complete the assessment more quickly than they otherwise would have, reducing the reliability of the Canvas student-level mean as an outcome measure. Additionally, despite being available for one week following the lecture, the post-assessment was not completed by a substantial portion of students, further limiting the Canvas mean. For these reasons, the item-level mean is considered the more reliable indicator of knowledge change in this study, as it is calculated per question rather than per student and is therefore less susceptible to the influence of individual student engagement at the time of assessment completion. Future iterations of this study should administer the post-assessment at a separate time point, removed from the lecture session itself.

Relevance to Physician Assistant Education

These findings take on greater significance when considered in the context of current PA and medical student cardiology education. Existing literature suggests that cardiology curricula at both the medical student and PA student level tend to emphasize pattern recognition of rhythms and pathologies rather than foundational instruction in electrophysiology and ECG acquisition mechanics.[4,5,6] The present data suggest that supplemental instruction targeting these foundational areas, whether embedded within the existing cardiology course or delivered as a separate session, provides measurable benefit to students. If this type of curriculum were integrated more systematically, it could facilitate a deeper understanding of the cardiac pathology students are expected to recognize clinically, as students would better understand the underlying basis for the findings they are asked to interpret.

Research on supplemental cardiology education for PA students specifically is limited, and evidence-based guidance on effective teaching modalities for ECG content in PA programs is largely absent from the literature.[13] This study helps address that gap and offers a model for targeted ECG

instruction that is feasible within existing program structures. Furthermore, while some may question whether ECG acquisition is a necessary competency for graduating physician assistants given that the skill may not be performed regularly in all clinical settings, the ability to correctly interpret an ECG depends in part on understanding how it is acquired and where errors can be introduced.[8] With 96% of students expressing that this education should be part of their curriculum, there is clear learner-driven demand for this content that programs should consider.

Domain-Level Findings

The Planes and Orientation domain demonstrated the greatest overall improvement of any domain, increasing from 73% to 94% correct with a medium average effect size (Cohen's h = 0.598). This finding is particularly noteworthy because this domain encompasses some of the more conceptually abstract content within ECG education, specifically the spatial relationship between cardiac anatomy and the views provided by different ECG lead groupings. Students may enter the cardiology curriculum with an understanding of which leads to examine for particular pathologies but without a clear understanding of why those leads are diagnostically relevant. For example, students may recognize that anterior ST-elevation myocardial infarction is identified in the precordial leads without fully understanding that those leads derive their diagnostic value from the horizontal plane view they provide of the anterior left ventricle. The gains observed in this domain suggest that explicitly addressing this foundational spatial reasoning can be effective even in a single session, and that further curricular time dedicated to this content could yield continued benefit.

The Errors and Artifact domain presented the most complex pattern of results. While the domain showed only modest overall improvement (62% to 70% correct, average h = 0.183), this aggregate figure obscures notable within-domain variation. The Remember-level question within this domain, which addressed recognition of right arm-left arm electrode reversal, demonstrated one of the largest individual gains in the study (49% to 92%, h = 1.011). In contrast, the Understand, Apply, and Analyze questions within the same domain showed little or no improvement. This pattern suggests that students became

better able to identify and name specific acquisition errors discussed during the session but did not develop deeper understanding of the underlying mechanisms or clinical implications of those errors. This interpretation is consistent with student feedback requesting more clinical case-based comparison of artifact versus true pathology. Future iterations of this curriculum should prioritize case-based instruction for artifact content, presenting students with paired ECG examples that require active comparison between technical errors and genuine cardiac findings.

Bloom's Taxonomy Level Findings

When performance was examined by Bloom's taxonomy cognitive level, Remember and Apply questions demonstrated the greatest improvement, each showing a small effect size (average $h = 0.449$ and 0.380, respectively), while Understand and Analyze questions showed negligible change (average $h = 0.052$ and 0.118, respectively). Two interpretations are worth considering. First, the intervention was structured around foundational knowledge acquisition and practical application, which aligns well with the cognitive demands of Remember and Apply questions; higher-order synthesis and analysis may not have been emphasized sufficiently to produce gains at those levels. Second, Understand and Analyze questions entered the post-assessment with already relatively high pre-assessment performance (82% and 76%, respectively), leaving less room for detectable improvement compared to Apply-level questions, which began at only 55% correct. Both factors likely played a role, and future curriculum development should consider whether targeted higher-order reasoning activities, such as case-based clinical scenarios, could improve performance at the Understand and Analyze levels.

In-Class Activity Findings

The in-class electrode labeling activity, completed by 36 students prior to any instruction, provided compelling baseline evidence that meaningful knowledge gaps in ECG acquisition were present entering the session. The overall correct response rate of 31% (mean 6.2/20 points) across anatomy and diagram portions indicates that most students lacked accurate knowledge of electrode placement at a level

required for correct ECG acquisition. Students demonstrated greater accuracy for limb leads (40% correct) than precordial leads (21% correct), suggesting that precordial lead placement, which requires precise intercostal space identification, is a particularly undertaught area. A common source of error on the diagram portion appeared to be difficulty correctly identifying intercostal space levels, with many students placing electrodes in the correct general region but at an incorrect intercostal space. This points to a potential gap in applied anatomy education that could be addressed within the first-year curriculum to support ECG acquisition competency.

The contrast between these activity results and students' pre-assessment confidence data is notable. Despite an overall electrode labeling accuracy of only 31%, 54% of students reported moderate or high confidence in their ability to correctly perform a 12-lead ECG prior to the intervention. This gap is particularly striking given that 38% of students reported having performed more than 15 ECGs prior to the session, suggesting that prior clinical exposure did not reliably translate into accurate foundational knowledge of electrode placement. Together these findings suggest that students may overestimate their practical ECG competency when not given the opportunity to directly demonstrate it, a pattern consistent with broader findings in health professions education on the disconnect between self-assessed and objectively measured clinical skill.[16,17]

A similar pattern was observed with respect to understanding of augmented limb leads. During the lecture session, when students were asked by a show of hands whether they understood what aVR, aVL, and aVF stood for, the majority of the class indicated they did not. This informal observation, combined with the pre-assessment finding that 64% of students felt moderately or very confident in their understanding of how an ECG assesses cardiac activity, further reinforces the concern that student confidence in this area may not accurately reflect their actual foundational understanding. These findings collectively underscore the value of active learning components that require students to demonstrate knowledge rather than simply self-report it.[18]

Confidence and Perceptual Findings

Following the intervention, students' confidence in their ability to correctly place electrodes and independently perform a 12-lead ECG increased substantially, with the proportion reporting moderate or high confidence rising from 54% to 84% (+30 percentage points). This improvement aligns with the knowledge gains observed in the Lead Placement and Planes and Orientation domains and suggests the intervention successfully addressed some of the practical competency uncertainty students brought to the session. It is worth noting that programs should not assume incoming students have consolidated ECG acquisition skills based on prior patient care experience, as 41% of students reported never having performed a 12-lead ECG prior to the session, highlighting the substantial variability in baseline clinical exposure within a single cohort.

Confidence in distinguishing true cardiac pathology from technical artifact or error also improved, with the proportion of students reporting moderate or high confidence increasing from 13% to 40% (+27 percentage points). Despite this gain, 60% of post-assessment respondents continued to rate their confidence in artifact discrimination as low or minimal. This finding is consistent with the mixed Errors and Artifact domain results and reflects the reality that a single session touching on one specific artifact type is unlikely to produce broad competency in artifact recognition. This area represents a clear and specific target for future curriculum expansion, a conclusion reinforced by student qualitative feedback requesting additional case-based artifact versus pathology instruction.

Student Perceptual and Qualitative Findings

Student perceptions of the intervention were strongly favorable. Ninety-six percent of students agreed or strongly agreed that the in-class electrode labeling activity helped them recognize gaps in their baseline understanding of ECG acquisition, a finding that directly supports the active learning rationale underlying the design of the active-learning session. Research in health professions education consistently supports the superiority of active learning over passive didactic instruction for developing durable clinical knowledge and skill,[19] and the data from this study suggest that even a brief structured activity requiring students to demonstrate electrode placement knowledge can produce this recognition of knowledge gaps.

The student response quoted in the results section captures this dynamic directly, describing how the act of physically drawing electrode locations revealed gaps that passive reading had not.

Ninety-six percent of students also agreed or strongly agreed that participating in hands-on ECG electrode placement on a person would have further improved their understanding of the material. This finding is particularly meaningful given that the original study design included a hands-on ECG skills component in which students would have practiced electrode placement on a willing classmate; this element was ultimately removed prior to implementation following faculty review. The sustained high level of interest in hands-on ECG training expressed independently by students provides strong justification for revisiting this decision. If performing ECGs on classmates continues to be considered inappropriate, programs should explore alternatives such as the use of standardized patients or simulation models for ECG acquisition skills practice.

Thematic analysis of open-response qualitative feedback identified three primary student preferences regarding the timing and format of future ECG instruction: integration during the cardiology unit, incorporation into a structured skills laboratory modeled after the existing point-of-care ultrasound curriculum, and completion prior to the start of clinical year. These themes collectively suggest that students view ECG acquisition not as a peripheral skill but as a core clinical competency that warrants dedicated curricular time and structured practice opportunities, consistent with recommendations in the PA education literature regarding clinical skills preparation.[20]

Limitations

Several limitations of this study warrant consideration. The most consequential limitation was the timing of post-assessment administration. Because most students completed the post-assessment immediately following the lecture session, many likely completed it more quickly than they otherwise would have, reducing the reliability of Canvas student-level performance data as an outcome measure.

Future studies should administer the post-assessment at a separate time point, ideally later the same day, to allow for more thoughtful responses.

A related limitation is the inequality in pre- and post-assessment sample sizes, with 39 students completing the pre-assessment and only 24 completing the post-assessment. The voluntary nature of both assessments introduces potential response bias, as students who chose to complete the post-assessment may represent a more engaged subset of the cohort, which could inflate post-assessment performance estimates. Future studies should consider making assessments a required course component while maintaining student anonymity to ensure more complete and representative data.

The use of aggregate rather than individual-level data represents an additional methodological limitation. Because Canvas quiz settings were configured to maintain anonymity between researchers and participants, individual pre-post score matching was not possible. This precluded the use of paired parametric or non-parametric statistical tests such as the paired t-test or Wilcoxon signed-rank test, requiring instead the use of Cohen’s h for independent proportions as the primary effect size measure. While Cohen's h is appropriate for comparing two proportions, the inability to link individual student scores limits the strength of the conclusions that can be drawn. Future studies should utilize an assessment platform or configuration that permits individual data linkage while maintaining participant confidentiality.

Because this study did not include a control group, it is difficult to conclude that the observed improvements were solely the result of the intervention. Without a comparison group, observed improvements could reflect other factors such as concurrent learning from other coursework rather than the intervention alone. Future research should incorporate a control group, such as a cohort receiving standard cardiology instruction without the supplemental session, to strengthen causal claims. Additionally, the absence of a comparison instructional format limits the ability to attribute observed gains to the active learning design specifically. It is possible that any structured review of ECG content

would produce similar improvement regardless of teaching methodology. Future studies should compare active learning directly against traditional didactic instruction to isolate the effect of teaching format.

Additional minor limitations include the occurrence of multiple-answer responses on four post-assessment perception items, which resulted in 25 recorded responses for those items despite 24 student participants. These items were reported using n=25 as the denominator, and the impact on reported percentages is negligible. Finally, this study was conducted with a single cohort at a single institution and should be interpreted with appropriate caution regarding generalizability, as curriculum structures, student backgrounds, and baseline ECG exposure vary across PA programs.

Future Directions

If this intervention is replicated or expanded, several modifications are recommended. Post-assessment administration should occur at a time removed from the lecture session, and an assessment platform or configuration allowing individual-level pre-post matching should be utilized. Making the assessments a required course component should be strongly considered to improve response rates and reduce selection bias. Including a control group in future studies would strengthen the ability to attribute observed improvements to the intervention. Additionally, a follow-up assessment at a later time point, such as at the end of the cardiology unit or during clinical year, would allow evaluation of whether knowledge gains from this session are retained over time.

From a curriculum design standpoint, the data from this study support several specific recommendations. Most importantly, a structured hands-on ECG acquisition skills laboratory should be developed and integrated into the cardiology unit, allowing students to practice electrode placement under supervision. Content addressing the discrimination of artifact from true pathology should be expanded and delivered using case-based teaching methods that present students with paired ECG examples requiring active clinical reasoning. Foundational electrophysiology content, including background on augmented limb leads and basic cardiac anatomy, should be explicitly addressed early in the cardiology

curriculum rather than assumed as background knowledge. Finally, the brief in-class electrode labeling activity used in this study represents a low-resource, high-impact active learning tool that could be incorporated into multiple points across the cardiology curriculum as a formative assessment strategy.

Conclusion

A single active, application-based ECG teaching session produced measurable improvements in first-year PA students' knowledge of cardiac electrophysiology and ECG acquisition, with item-level performance increasing by 10.3 percentage points and large effect sizes observed on questions addressing cardiac plane orientation and common acquisition errors. The greatest domain-level gains were observed in Planes and Orientation, while Remember and Apply-level questions demonstrated the strongest cognitive-level improvements. Student confidence in electrode placement and ECG performance improved substantially following the intervention, and students expressed near-universal support for the active learning components of the session and strong interest in hands-on ECG skills training. Persistent gaps in artifact recognition and higher-order ECG reasoning indicate areas requiring targeted future curriculum development. Taken together, these findings support the integration of dedicated electrophysiology and ECG acquisition instruction into PA cardiology curricula, including structured hands-on skills practice. Further research is needed to identify the most effective strategies for delivering this content within physician assistant training programs.

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Author Contributions

N. Jasion conceived the study, designed the intervention, collected and analyzed the data, and wrote the manuscript. E. Randolph, MMS, PA-C, contributed to the original study concept, assisted in the development of pre- and post-assessment questions, reviewed lecture content, and provided supervisory oversight and critical review of the manuscript throughout the project.

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