Innovation for accessible and secure voting: A review of the literature

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Abstract

Since 2002, when HAVA mandated that voting systems must make it possible for people with disabilities (including blind voters) to vote “independently and privately in the same manner as other voters”, there has been a tug-of-war between the requirements for accessible voting and secure elections. Despite significant improvements to voting system standards, there is no clear resolution to this on the horizon over 20 years later. There seems to be no clear path forward to accessible voting that does not add security risks or methods to secure elections that do not add barriers or burdens for voters with disabilities.

This review of the literature looks at the promises and challenges of innovations in end-to-end verifiable cryptography as an alternative to the paper-based ballots that are currently the most common model for software independence. The focus is on how innovative technologies might balance the burdens to voters (and election administration) with the value they add to election integrity.

Keywords

Ballots; end-to-end verifiable cryptography; innovation in elections; standards; accessible voting.

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Introduction

This paper starts with the observation that despite many other changes in elections since the Help America Vote Act was enacted in 2002, there has been little progress in solving the tug-of-war between the needs of accessible and secure elections. If anything, the advocates for the two perspectives have moved apart, each frustrated by the lack of progress.

We began this work with the insight that security innovations can add burdens for voters. And that making voting easier for people with disabilities—for example with completely electronic voting—creates risks to election integrity. As we dug into the literature, it was clear that there is little thoughtful analysis of the balance between promises of innovations and the challenges of burdens or risks they may introduce.

Too often, ideas are introduced without a clear view of the problem they can solve, the intended outcomes, and the challenges that the idea must overcome to be successfully added to the administration of elections. Worse, there seems to be little interdisciplinary work that brings together experts from the relevant fields of cybersecurity, disability rights, and election administration.

This siloing also produces a gap of core principles or goals, pitting legal rights against technical theory, neither considering the practical implications for election administration:

Accessible voting advocates start from the rights of individual voters with disabilities, including both legal protections and moral rights as citizens. They are backed by the history of legal rights from the broad Americans with Disabilities Act and the election-specific Help America Vote Act.

Cybersecurity advocates start from a systemic view of elections and the need to protect them from both malicious attacks and unintended errors that can go unnoticed in the process of an election.

Despite, and sometimes because of, progress in improving voting systems–both have also expanded their positions over the years, identifying new requirements and risks. On the disability side, the view of the audience pays more attention to including the needs of people with cognitive and intellectual disabilities including literacy. On the security side, there are expanded claims for what is required to ensure that ballots are both cast as intended (verifiability) and counted as cast (auditability). We should note here that like in many emerging fields, definitions and terminology are not always used consistently. “Verify” is one such word that is used in several ways depending on the context.

In addition, the election environment itself has changed:

The rapid expansion of voting by mail from an alternative for special circumstances to the default method of voting did not include a robust consideration of how voters with print disabilities can participate equally.

Increased use of modern audit methods has come at the same time as a growing mistrust in elections administration amplified not only a desire for hand-marked paper ballots but also for hand-counting of all ballots.

Modernizations like expanded early voting and postmark (vs. delivery) deadlines for mail ballots added complexity to election administration.

The increased cyber attacks, politically motivated mis/disinformation campaigns, and the malicious use of AI have changed the nature of election administration.

Only rarely have these changes included a discovery process rooted in the context of elections. As a result, voters' and election administrators' needs, attitudes, and behaviors were often left out of early consideration of new ideas. The call for a human-centered design approach goes back to NIST's initial paper on usability and accessibility in 2004 [1]. Whether you call it universal design, design thinking, systems thinking, or any of the other labels, it is essentially a consultative process, in which all of the requirements are considered as a whole.

It seems clear that without some change, we will not be able to create a modern election system that is both accessible for all voters and can be conducted with a reasonable guarantee of the integrity of the process.

To understand what the research can tell us, we explored the literature on new and innovative voting systems looking for insights about how voters understand new election features and how they are introduced. We focused on the work to bring end-to-end verifiable cryptographic systems into U.S. elections but also considered related innovations and articles that offered insights into how voters' mental models of new systems affect their ability to use them effectively.

What this review does not include

Innovations are sometimes evaluated by comparing their benefits to the costs or risks of adopting them. Although all changes bring risks, this review does not include a discussion of the security risks of different technologies or the cost of implementation.

It can also be tempting to consider a quantitative approach to evaluating the burden of a new technology, for example, identifying the number of voters likely to be affected. In our view, innovations have to both solve known problems and avoid adding complexity or burden to the voting process. Voters with disabilities have the right to independent and private voting, just as other voters do, so a successful innovation has to be designed for universal access.

Innovations in election administration

Elections are complex systems that include elements of government service design, document management, and technology systems. Changes to elections, from implementing new voting systems to adopting new methods of voting or procedures, can take a year or more to plan.

One dimension—the size of the office—provides one view of the scale of the challenge of making any change. Elections are run by some 10,000 state, county, and city or township elections offices. According to the Partnership of Large Election Jurisdictions (https://taketheplej.org/), the 462 largest jurisdictions represent more than 66% of American voters. The smallest may be an office run by a part-time clerk. These offices administer elections with the help of over 1 million temporary workers, who run Election Day and early voting polling places and are the workforce for managing mail-in ballots.

Election administration, however, is not stagnant. New laws, new voting methods, the need to replace systems, and general updating to improve the conduct of elections go on all the time. We are therefore more concerned with the long-term burdens that might be introduced than the initial costs of adopting a new voting method or system.

Successful transformations take time, broad input, and support

We start with a brief look at some successful innovative transformations.

Three large jurisdictions made changes to their election administration in the last 10 years: Colorado, Los Angeles County, and New York City. The shared feature of these larger innovative transformations (and all the smaller ones that go on every year) is the time and internal and public consultation they took. This process allowed time to ensure that all of the different requirements for the new voting systems could be addressed.

The Colorado Method

In 2014, the State of Colorado adopted a new way of voting for the entire state, often called a "gold standard" because of the combination of features and the way it was adopted. The Colorado Method [2] includes sending mail ballots to every voter and opening Voter Service and Polling Centers (VSPCs) for 15 days before the election where voters can drop off a ballot, use accessible voting systems, and update their voter registration or register through Election Day. The state adopted a single voting system for use in all but two of the counties in a process that included pilot elections for candidate systems in both a large and small county.

Notably, the idea was supported by a broad coalition of disability and good-government advocates, and the final bill was drafted with substantial input from election officials. The state elections office also created software to enable the reform, including a state-wide poll book for use in the VSPCs. The collaboration over several years allowed consideration of technology, policy, implementation, costs, and the voter experience.

Los Angeles Voting Solutions for All People (VSAP)

Los Angeles County completely replaced its systems for in-person voting and for designing and counting ballots with the Voting Solutions for All People (VSAP),[3] designed and developed by the county. It was a 10-year process that included careful consultation and consideration of the impacts on the election of every aspect of the new system design. The journey from the Inkavote (a punch-card system adapted for ink instead of chads), led to a new mail-in ballot design being introduced in 2018, and a ballot marking device for in-person voting in 2020. The design process for VSAP overlapped with the California adoption of the Voter's Choice Act which built on the Colorado Model for moving from polling places to mail ballots and vote centers.

The design and discovery process included public opinion research, a process assessment, system design, system engineering and manufacturing, and certification and rollout. In addition to the technical and administrative issues, the process included usability testing and demo elections with over 5,000 people in addition to several advisory committees and many public meetings and demonstrations.

Accessible Vote-by-Mail

The rapid growth of voting by mail created a need for innovative solutions to make this method of voting accessible. Since its first use in 2015, accessible voting by mail (AVBM) is now in use in roughly half of the states, through several different vendors and systems created by state elections offices.

A NIST report [6] looked at whether there were procedural reasons why its use is not as widespread as might be expected, based on legal accessibility requirements. Interviews with product developers and officials in charge of running these systems showed that one of the pain points is moving ballot styles and voter data from the election management and voter registration systems to the ABVM systems. Few election systems have good data exchange formats, making both the transfer of ballots into the AVBM system and proofreading the ballots a pain point.

Moving from E2E-V research concepts to real elections

One of the challenges we found in reviewing the literature is that the early stages of innovation tend to focus on the technology itself, without strong input from election officials, or other experts. While this provides opportunities for considering new ideas for voting, prototypes often fail to consider voters' habits, assumptions, or mental models. The result is an innovation that may be technically defensible, but hard to implement in a polling place or which asks voters to perform unexpected actions during the voting process.

Early explorations focus on the technology, not the voter experience

In two studies [7, 8], the unintuitive and unexpected requirements of those early E2EV systems led to participants in usability testing not being able to cast their ballots or verify their votes accurately in unacceptably large numbers. The studies also reported frustration or confusion about the procedures, suggesting that these early designs might have solved a technical problem, but at the cost of added burden to voting and election administration.

Interactions in early E2E demonstrations

System	Action required	Issues
Helios (Electronic)	Voters marked a ballot and then checked in through a complicated login process before being able to cast their ballot	Changes current procedure Complex authentication Voter confusion about casting
Prêt-á-voter (Paper)	Voters are directed to rip the ballot to separate the list of candidate names from the selection marks before casting their ballot	Novel step of shredding half of a ballot is hard to explain Risks mistakes in which half is cast and which is discarded Ballots cannot be audited
Scantegrity(Paper)	Ballots had to be marked with a special pen that revealed invisible ink confirmation codes for confirming (after the election) that the ballot was cast	Voters required to transcribe confirmation codes and ballot ID
Benaloh Challenge (multiple systems)	Voters mark a ballot and then decide whether to cast that ballot or verify it and then discard it	Complex procedure in the polling place Voters cannot always determine success

Early use in real elections brings new challenges

Those early explorations are key to establishing the viability of new technology but also show that accounting for people's expectations and assumptions is critical for widespread acceptance of a "new normal". Updated versions of the systems and use in new elections often led to better success but also raised issues about ways to implement a new system.

Context for use in real elections

System	Election	Process and features
Helios 2.0 (2008) [9]	University President Electronic, remote voting 4000 ballots cast	Voters registered and created an alias to identify themselves Voting took place on a separate platform. Voters could cast more than one ballot with only the last one counted An open audit of the ballots was available after the election
Scantegrity II (2009) [10]	Takoma Park, MD Mayor and Council 1728 ballots cast	This was a ranked-choice election. The previous ballot design was maintained as much as possible for familiarity. Voters mark optical can ballots with double-ended decoder pens Voters had to copy down code numbers to use for later confirmation Voters had two websites available for confirmation

Both elections included opportunities for voter feedback. Some comments focused on specific ballot design issues but many were about the new activities or instructions. Predictably, the most novel feature, the option to confirm or verify that a ballot was counted, got many comments, as did confusion about instructions.

More importantly, reports from both elections talked about the careful planning and coordination with the university or election authority that was needed. The Scantegrity II team wrote that:

> "As is common with many projects, too much was left until the last minute. Better project management would have been helpful, and key aspects should have been finalized earlier. Materials and procedures should be more extensively tested beforehand.
>
> One of the most important lessons learned is the value of close collaboration and clear communication between election officials and the election system providers (whether they be researchers or vendors)." [10, p14]

The Helios 2 report was happy with the "overall acceptance" but also hinted at the challenges of changing an entire way of voting:

> "Given our experience, we believe that when one decides to introduce a new voting system, mimicking the current system in place is typically not appropriate. Instead, one should introduce all changes as early as possible in the migration, thereby avoiding the

shortcomings of repeated changes and giving voters the maximal amount of time to become accustomed to all changes." [9, p12]

Shifting into developing full systems

Work that followed built on those early experiments. Three projects are examples of the value of working in a multi-disciplinary way within the opportunities and constraints of current election laws and procedures.

- STAR-Vote [11] was a collaboration between the host election office in Travis County, Texas elections office, technology experts, and human factors researchers. Using what they learned in usability testing other systems and their prototypes, they were able to reduce the voter burden and achieve better success rates in testing [12]. Ultimately, STAR-Vote did not succeed as a product despite better success rates. Although the county issued a Request for Proposals to build it, no vendor submitted a proposal at an acceptable price.
- ElectionGuard [13] picked up much of the technical development from STAR-Vote and focused on what it would take to turn E2E-V technology into real elections as a full product. Their approach was to adapt a standard voting process unobtrusively. The E2E-V cryptography was incorporated into a commercial ballot scanner, allowing voters to mark and cast their ballots as usual, and receive a confirmation code at the end of the process. Pilot elections tested the technology in a very small special judicial election (Wisconsin, 2019), a single precinct (Franklin County, Idaho 2022)[14], and all voters in a municipal election (College Park, Maryland, 20230 [15]. The ElectionGuard team worked closely with voting system vendors on the implementation, election administrators on procedures for poll workers, and education materials for voters.
- VoteHub [16] uses E2E-V as part of their mobile application for absentee voting. They have focused on making voting more accessible to voters with disabilities, older voters, and GenZ first-time voters. Notably, they are pursuing a user-centered design process, using mock elections and usability testing to explore the mental models that participants form while voting. In three separate projects in 2023, over 175 voters tested versions of the system.[17]

In both VoteHub and ElectionGuard, there are two actions that voters can take:

- Confirm that their ballot counted: Using a code presented after casting, they can go to a separate website to see that their code is included in the list of ballots counted.
- Ballot check: Completing a Benaloh Challenge in which they can ask for the ballot to be decrypted, so they can check the selections that were recorded.

In the VoteHub testing, one of their most critical tests of the process was whether voters could successfully perform the optional check to confirm that their vote counted. This added steps to voting, so the number completing a ballot check is a measure of whether participants understood it to be part of voting and its value in election integrity. The percentage of voters performing the check as part of these studies is larger than likely needed for security.

VoteHub usability testing

Study	About the participants	Number of participants	Number completing a ballot check	Additional notes
First Time Voters [18] (Feb 2023)	High school students under 18 years old	50	40%	67% said it was easy to complete the check
GenZ voters [19] (July 2023)	Participants recruited through social media	22	45%	108 people signed up. Reliance on email after the initial registration may have reduced participation for this age group
Voters with visual disabilities [20] (Aug and Dec 2023)	Blind and Low vision voters	52 (Aug) 63 (Nov)	62%	92% want to use mobile voting in the future

Perhaps it is inevitable that technologists focus on technology, but the three projects that worked with election officials took big steps toward implementing E2E-V. STAR-Vote, ElectionGuard, and VoteHub's progress demonstrates that understanding expectations, assumptions, and mental models is an important step that can speed the acceptance of innovative technology.

As an example of early collaboration seeding innovation, the EAC-funded Accessible Voting Technology Initiative [21] included early "design thinking" workshops that brought together election officials, technology designers, developers, people with disabilities, and disability advocates to brainstorm ideas to improve accessible voting. One concept, the Sample Ballot & Information System, became the Los Angeles Interactive Sample Ballot [22] (or Poll Pass) that allows voters to save time while voting in person by marking their ballot at home. It enables voters with disabilities to use their personal assistive technology. This concept combined a technology idea with the voter need to create an accessible remote ballot marking tool as part of the Voting Solution for All People (VSAP).

Mental models are critical to successful innovations

The role of mental models in a literature review on voter verification identified mental models as being formed by voter experiences and what they understand about the actions they are asked or required to complete. The reason for understanding mental models is to identify the "gaps between what people say and how they behave and a complex interaction between awareness or understanding of the problem."[23]

Privacy settings are another field in which the adoption of new technology has suffered from mismatches between beliefs, understanding, and action. As products began adding privacy settings, there was concern that users would not be able to successfully use the controls to set their desired level of privacy.

One study [24] explored mental models of privacy as a way of gaining a better understanding of how people thought about privacy. They asked people to complete a participatory exercise in which they created illustrations with captions to explain what privacy means to them. The researchers then analyzed the drawing for concepts and metaphors that could be used to design better digital privacy controls. Rather than relying on their participants' understanding of technical language or making assumptions about their level of knowledge about digital privacy, they were able to identify differences they could attribute to demographics, experience, and attitudes about public and private space.

Other studies of advanced technology in elections show that mental models have to be considered along with design details to successfully take human behaviors into account. In addition to the basic usability of the interaction, they include the level of trust in the current system,[25] the experience of different types of voters,[26] beliefs about elections [27], fluency with technology,[28] and the timing of when the new actions are introduced [29]

Voters expect voting to be easy, so they may ignore voter education

Explaining the changes that E2E-V brings to an election is a critical part of implementation. Voters need to learn what they have to do as well as why they are doing it. Even projects that put effort into creating multi-layered voter education found it hard to get people to pay attention to the information. The pilot teams used many ways of communicating, including:

- Election websites
- Local newspapers or office newsletters
- Public meetings or forums
- Information sent by postal mail or emailed directly to voters
- Posters and other signage at the polling place
- Information or instructions handed to voters as they entered or posted in the voting booth
- Information on the ballot
- Verbal instructions from poll workers

Even in a high-salience election, news about a new voting method can be lost within the more immediately needed details of when and where the election will be held.

For example, when Pennsylvania introduced an accessible option for voting by mail, only a few voters used it. Interviews with voters for a news article [30] reported several reasons:

- They didn't know about it.

- It was not a complete solution to their needs.
- They found the new system too complicated
- They found the instructions confusing.

Good design and instructions lead to acceptance

It can be hard to separate the inherent technical complexity of adding E2E-V cryptography to a voting system from the usability of the voter experience. However, even in research and reports about the technical implementation, it is clear that making the process understandable and usable for voters is important for the success of a new system.

Innovations are likely to be perceived as having a high burden just because they are new and require more cognition until the innovation becomes the new norm. Good design and instructions help voters make the transition from old to new ways of voting.

This section discusses factors in usability that emerge from reports of voter success and difficulties in marking and casting a ballot.

Voter burden is subjective

The true measurement of how much burden a process adds to the voting experience isn't a simple measurement of time. It is subjective as voters balance the perceived value with perceived effort. The bias of their own past experiences and what they believe to be true may differ from objective measurements. For example:

- A study of voter review and verification of their ballots [31] showed that voters using a ballot marking device (BMD) for the first time assumed that it took longer than hand marking a ballot but empirical measurements showed that the BMD was faster.
- A study comparing two surveys of voter attitudes about voting systems found that direct recording (DRE) electronic voting systems were not only preferred by those who used those systems but even by people who voted on scanned paper ballots, showing wider support for these systems than experts assumed. [32]
- A study found that voters can be motivated to take extra steps, such as checking their ballot for accuracy. This suggests that changing the environment and how the new activity is introduced can increase acceptance. [33]
- A study of voter perceptions of voting system usability found that all aspects of the systems got higher subjective ratings depending on the characteristics of a photograph of a polling place they were shown. When they believed that the environment was conducive to privacy and easy navigation in the space, they were pre-conditioned to believe that the voting system was better. [34]

These conclusions can seem obvious in retrospect, but they are an important reminder that attitudes make a difference to both perceptions of usability and voter performance.

Looking at the development of E2E-V from an innovative idea to a functional part of voting, acceptance of this new technology depends less on the technical security properties than on how easily voters understand the specific actions they are asked to take during and after voting.

A study at Rice University [35] explored whether voters could tell the difference between actual and fake security features. They compared voting with a conventional paper ballot, one with information that claimed to add security (but which had no real value), and one with E2E-V features. When asked to rate the security of each system, the 90 students who participated in the study rated the ballot with advanced security features as more secure. This study provides some confidence that voters will be able to recognize better security in a real-world implementation.

Familiar, minimal ballot design builds voter confidence

Innovations may introduce new requirements for the ballot design, but getting the ballot design right is a key to building a sense of confidence. If voters assume that marking a ballot should be easy, any change that makes it feel unfamiliar or difficult may reduce trust in the overall innovation.

General research on ballot design also confirms the importance of a ballot design that lets voters concentrate on marking their ballot as they intend, rather than getting caught up in deciphering the user interface of a BMD or the layout of a ballot [1, 26, 28]. The Anywhere Ballot design principles describe the "mission" of a ballot to "support voters through a clear, tested, minimalist design" and include "Make the ballot look easy to read" as one of the principles [36]

All of the more recent pilots of E2E-V systems have tried to minimize changes to the ballot design. As the researchers wrote about the Scantegrity II pilot:

> "The ballot used for the 2009 election was based on ballots used for the 2007 election. We made the conscious choice to modify (as little as possible) a design already used successfully in a past election, and not to use the ballot we had designed for the mock election. The main reason for reusing the ballot design was that it would be familiar to voters." [10 p8]

VoteHub [16] focused part of its design efforts to ensuring that the electronic ballot marking interface would be fully accessible and usable. The mobile platform was itself an innovation, so they worked to keep the design familiar and easy to learn through their usability testing. ElectionGuard [14,15] used the standard ballot design from Hart InterCivic, the manufacturer of the scanners used in those pilots.

These decisions to keep the existing ballots meant that most voters found it easy to mark their ballots in these early elections, even if there were usability challenges in other parts of the process. The take aw As long as that is familiar, feel on safe ground.

Focus instructions on actions voters must take

Similarly, Instructions are an integral part of the voting experience; voters are given instructions in many places (registration, voter guides, mail-in ballots, paper ballots, signage at polling places, instructions for marking the ballot, instructions for casting the ballot, etc.). Reducing voter burden by keeping instructions minimal also helps ease new technologies into the voting process.

As in ballot design, the goal for writing instructions for new voting systems is to find the balance between the information voters need at that moment and the natural urge to explain all the details.

Testing is also important, even when experts have created the instructions. Tests with voters with disabilities of a new accessible ballot marking tool for mail ballots revealed problems with the instructions that would have prevented returning a ballot successfully. In many cases, the solutions included both shortening and simplifying instructions text as well as removing "unnecessary distractions (such as links to download supported browsers)"[36] Similar work to simplify instructions and explanations, rather than adding words, worked effectively in helping voters move seamlessly through the voting process for a new ballot design. [37]

For in-person voting procedures, the instructions that poll workers give voters and the flow through the polling place matter as well.

- In a research project testing the ability of voters to detect malicious errors on their ballot, researchers varied the script for what mock poll workers told voters to do and where the message was delivered. By adjusting the instructions and process through a series of experiments, they were able to increase the number of "voters" reporting an error from less than 10% to over 85%. [38]
- In both ElectionGuard pilots [14,15] poll workers' verbal instructions were tested and iterated through each of the four election days. The researchers, election office, and poll workers were all actively involved in fine-tuning the timing and content of the messages to make them more effective—and usually shorter.

Terminology helps frame innovations in ways that resonate with voters

Preparations for the ElectionGuard pilots, [14,15] included research to explore what terminology and perspectives made sense to voters without the full technical context. The research behind those choices included asking people to read versions short introduction to ElectionGuard, pick the ones they liked best, and then explain what each meant to the researchers. The phrases that had that had the most resonance were then used as the basis for the voter information materials. They included [14, p19]:

- The ability to take action on your own to check, confirm, or verify
- The importance of independent verification
- The ability to test the system first

The most important piece was a handout given to each voter that had instructions and served as a place to hold the "ticket" with the confirmation code. The instructions emphasized that voting was the same as usual, along with instructions for confirming that their ballot was counted, and a link to the election website for more details. Instead of focusing on teaching voters about the technology, the information framed the innovation as one part of the election.

Conclusions

Even if well-designed and usable, voters also have to perceive new features for voting and elections as useful. How an innovative idea is framed is a key to that perception.

A larger challenge for introducing technical innovations is that terminology may be unfamiliar, either because it is from a technology field or because it is an general term drafted into use to explain something new. The research and development team understands the context and meaning, but the meaning may not be clear to a general audience. Testing instructions is the key to bridging this gap. [39] What seems easy to someone who already understands a procedure may not be understandable to a voter.

For example, successful Election Guard pilots in 2022 and 2023 [14, 15] concentrated on just telling voters what they needed to do rather than lengthy explanations about the E2EV process. For example, in testing a one-sentence introduction, some important concepts emerged from participant comments: [14, p19]

- The ability to take action on your own to confirm, or verify
- The importance of independent verification
- The ability to test the system first

The first two of these points were included in the final version of shortest introduction to ElectionGuard, creating a succinct, resonant statement of the value of the innovations

> "With ElectionGuard, you know your vote counted, and have independent verification that the elections results are correct."

A layered approach to implementation includes:

- Supporting voters and poll workers during voting with brief how-to instructions
- Providing minimal explanations to provide context and concept
- Using (and testing) terminology that makes sense to non-technical audiences
- Making more detailed information available for those interested

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