CDS Connect

Maintenance and Update

FINAL REPORT

(Year 6 of CDS Connect)

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Rockville, MD 20857
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Executive Summary

Healthcare is undergoing a digital revolution that will lead to innovations in using technology and data to impact care. As part of the Agency for Healthcare Research and Quality's (AHRQ's) clinical decision support (CDS) initiative, the CDS Connect project was launched in 2016 to put patient-centered outcomes research (PCOR) findings into practice. CDS Connect provides a web-based public platform for integrating evidence-based care more rapidly into clinical practice through electronic health systems.

The sixth year of the CDS Connect[1] project initially focused on system maintenance and updates to ensure that the tools remained shareable, standards-based, and publicly available, with a shift after the first quarter of the project to supporting other AHRQ initiatives. This annual report organizes the project's year-long accomplishments into four task areas: Task Management, Trust Framework, Standards Conformance, and Outreach.

Task Management (Manage Project Resources; Section 2)

With reduced tasking in Year 6 the CDS Connect project team (hereafter "the team") was leaner, primarily with a single lead and support staff across respective tasks.

Trust Framework (Prioritize Activities Based on Promotion of Trust; Section 3)

The team engaged with end users and other stakeholders to identify and prioritize updates. This activity resulted in a framework focused on two primary "must have" themes and one secondary "should have" theme for CDS Connect updates.

The primary themes were "must have"—

- Enforce Standards Compliance (CDS Artifacts): Update CDS artifacts already in the Repository to ensure compliance with applicable standards.

Other themes were evenly supported, including "Expand the Repository," "Increase Trust," and "Expand the Use of Existing Artifacts."

**Standards Conformance
(Ensure that Tools Adhere to Standards and are Innovative; Sections 4 – 7)**

CDS Connect tools and artifacts are more likely to be used if they adhere to existing, widely accepted standards and if they include useful innovations for end users. During this period of

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[1] The CDS Connect Maintenance and Update task order is in its second year, while the Health Federally Funded Research and Development Center's (FFRDC) overall support to AHRQ for the CDS Connect project is in Year 6, as referenced throughout this Final Report.

maintenance and update, the team introduced the following improvements based on the selected themes in the Trust Framework task:

- Implemented a standardized process to review and update (where needed) all CDS artifacts in the CDS Connect Repository.
- Updated CDS Connect project artifacts to follow best practices for Clinical Quality Language (CQL) development and reflect evidence updates from trusted clinical sources.
- Upgraded the CDS Connect Repository to Drupal 9 for ongoing vendor support.
- Developed the Repository User Guide.
- Created tiles and landing page for Clinical Decision Support Innovation Collaborative (CDSiC) project.
- Enhanced CDS Authoring Tool capabilities related to FHIR versions, artifact downloads, system integration, usability, and maintainability.
- Continued to maintain open-source software offerings to use latest libraries, including updated libraries for CQL execution.
- Continued the "Lessons Learned" series for the CDS Connect Work Group (WG), a community of more than 140 CDS members who provide diverse perspectives and help the team identify and prioritize key features and capabilities for CDS Connect.

Outreach (Engage with the CDS Community; Section 8)

Engaging with the CDS community through various channels promotes adoption of CDS Connect and increases use of the resources. During Year 6, the team continued to adapt to varied engagement formats and redirection from AHRQ on CDS community needs. The team engaged with the CDS community in the following ways:

- Participated in one in-person conference at the start of the year, with a focus on the use of CQL and the CDS Authoring Tool.
- Developed handouts and prioritized patient partnering in CDS through expansion of the Patient-Partnering Panel held during Year 5 of the project.
- Collaborated and supported AHRQ's CDSiC project and technical migration to Amazon Web Servicers (AWS) secure enclave.

These accomplishments during Year 6—primarily in the areas of prioritization of CDS needs in development and implementation, particularly with patient partnering—will enable the team to further its success in any possible future phases of the CDS Connect project.

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1. Introduction

As the lead Federal agency charged with improving the quality and safety of America's healthcare system, The Agency for Healthcare Research and Quality (AHRQ) develops the knowledge, tools, and data needed by researchers and clinicians to advance safe, high-quality, and patient-centered care.

To support the evolution of health information technology (IT), AHRQ's Digital Healthcare Research Program funds research to create actionable findings and supports the implementation of those findings as part of cutting-edge clinical practice.

AHRQ helps clinicians and their teams advance a continuous stream of research findings, clinical practice guidelines, and best practices into real-world clinical care through technical products such as clinical decision support (CDS).

The CDS Connect project plays an essential part in AHRQ's patient-centered outcomes research (PCOR) CDS Initiative (as shown in Figure 1). Starting its work in 2016, CDS Connect has become a publicly available infrastructure for sharing interoperable, standards-based CDS.

The first 3 years of the project focused on initial development and proof-of-concept activities. CDS Connect began its next phase of activities in the following 3 years by advancing the resources included in the platform, updating components based on current standards, and building awareness and use of its capabilities by the CDS community at large. Final reports from prior project years are available on CDS Connect. Overall, CDS Connect continues toward recognition as a national hub for standards-based CDS development and implementation.

Stakeholders rely on CDS Connect for its interoperable tools and resources, and they expect the content will adhere to clinical and technical standards. In the first part of year 6, the team focused on key updates to CDS Connect's underlying technologies and knowledge resources to ensure the system is well maintained and innovative. These updates require specialized testing protocols and intimate knowledge of resources previously developed by the CDS Connect project. These key updates are elaborated on in sections four through eight of this report. The remainder of the project year prioritized providing technical support to other AHRQ initiatives, including an Enclave Migration and CDSiC project. Details related to these efforts are described in the following sections below.
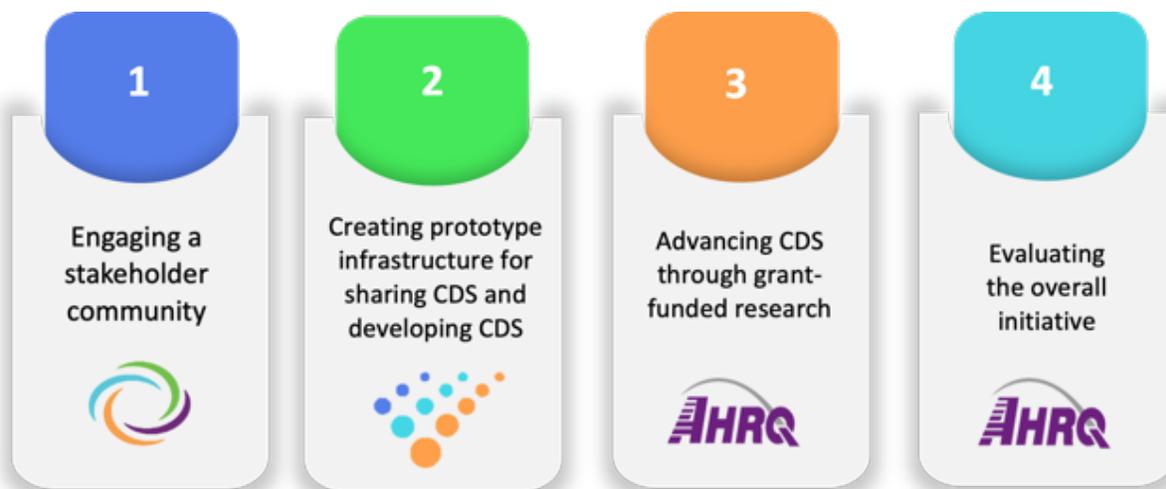
Figure 1. AHRQ's PCOR CDS Initiative

The resources available on the CDS Connect platform include—

- **Authoring Tool**: Open-source software for building CDS artifacts.
- **Repository**: A platform for managing and sharing CDS artifacts, including artifacts developed by The MITRE Corporation (MITRE) and others (e.g., Centers for Disease Control and Prevention [CDC], Children's Hospital of Philadelphia).
- **Prototype Tools**: Tools for testing and integrating CDS into health systems.
- **CDS Connect Work Group (WG)**: A group of CDS community members who provided diverse perspectives in identifying and prioritizing key features and capabilities for CDS Connect. The WG held its last meeting in June 2022.
- **Pilots**: Proof-of-concept demonstrations based on CDS artifact use cases and testing in live clinical and/or production settings (pilot reports are available to provide insights on implementation).

1.1   CDS Connect Project Tasks

During Year 6, the team focused on four task areas:

Task Management (Section 2): Ensure effective project operations, including staffing, budgeting, invoicing, delivery, quality assurance, and related activities.

Trust Framework (Section 3): Build on the values set forth in the 2018 Patient-Centered CDS Learning Network white paper[2] by prioritizing enhancements to CDS Connect based on identified themes and attributes.

Standards Conformance (Sections 4 – 7): Maintain and update CDS Connect to meet stakeholder needs and adhere to industry CDS standards.

Outreach (Section 8): Learn from stakeholders about how to improve CDS Connect for their benefit by conducting meetings, notably through the WG, demonstrations, and presentations at conferences, as well as support collaborative efforts across AHRQ.

1.2   CDS Connect Year 6 Milestones and Accomplishments

The team achieved the following key milestones and accomplishments in Year 6, spanning the entire CDS Connect platform:

1.2.1   Repository

- Continued development and deployment of Clinical Practice Guidelines (CPG)-on-Fast Healthcare Interoperability Resources (FHIR)-based artifact data model in the Repository.
- Completed the Drupal 9 upgrade to maintain support and adopt best practices.
- Improved the CDS artifact publishing process by beginning development (as of the writing of this report this feature is in development) of a notification for CDS Connect administrators of when an artifact has moved to the "requests review" status.
- Simplified the development and deployment process for Repository updates.

1.2.2   Website

- Developed the Repository User Guide.
- Developed and integrated the CDSiC tile and landing page on CDS Home page.

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[2] Richardson, J.E., Middleton, B., Platt, J.E., and Blumenfeld, B.H. (2020). Recommendations for Building and Maintaining Trust in Clinical Decision Support Knowledge Artifacts. Learning Health Systems. Available: https://onlinelibrary.wiley.com/doi/full/10.1002/lrh2.10208.

1.2.3 Authoring Tool

- Added support for authoring, uploading, testing, and downloading artifacts using FHIR version 4.0.1.
- Extended artifact downloads to include Expression Logical Model (ELM) definitions in Extensible Markup Language (XML) format.
- Introduced CDS Authoring Tool Terms and Conditions and a prompt for users to accept them.
- Implemented usability enhancements by improving visualization, layout, and user interaction.
- Integrated support for configuring secure protocols to host the application and interact with the user directory.
- Improved the code base to simplify maintenance and support reuse of CDS Authoring Tool components.

1.2.4 Prototype Tools

- Updated the Clinical Quality Language (CQL) Services, CQL Testing Framework, and Pain Management Summary to use current software libraries for CQL execution and other necessary components of the tools.
- Integrated the Factors to Consider in Managing Chronic Pain 2022 CQL updates into the Pain Management Summary.

1.2.5 CDS Artifacts

- Developed and posted enhanced review and update guidance for all CDS Connect authors.
- Updated CQL logic to follow best practices for CQL authoring as well as to reflect evidence updates where applicable.
- Revised metadata and implementation guides (IGs) for each MITRE-authored artifact to reflect recent changes in guidelines, value sets, and CQL on which they are based.
- Advised AHRQ on retiring or updating out of cycle artifacts to retain trust in the available content.

1.2.6 Work Group

- Prioritized the CDS Connect development efforts for expanding the Repository, increasing trust, and expanding the use of existing artifacts.
- Gathered input on best practices for artifact versioning and documenting changes to posted artifacts.
- Hosted discussions with external groups about their experiences with patient partnering.
- Reviewed the materials the WG Patient-Partnering Panel subgroup developed.
- Continued discussions on how to best involve patients and caregivers in CDS development, implementation, and refinement.

1.2.7 Outreach

- Engaged in conference and peer-reviewed outreach activities to encourage use of CDS Connect tools.
- Prepared a peer-reviewed publication detailing the approach to implementing a governance process for CDS artifacts shared on CDS Connect.
- Provided technical support to AHRQ's Enclave Migration effort to create a secured space for AHRQ's Center for Evidence and Practice Improvement (CEPI) systems.
- Provided technical support to create a distributed development model in support of AHRQ's CDSiC project.

2. Task Management

The CDS Connect project team consists of a Project Leader, Deputy Project Leader, Technical Leads, Clinical Lead, and Task Leads. The team also continued working with a patient/caregiver activist, Danny van Leeuwen of HealthHats, who provides a unique perspective in the continued development of CDS Connect.

A streamlined development staff was used in Year 6 and in March 2022 was able to respond to an AHRQ-initiated shift in technical direction. This resulted in a reduced focus on immediate CDS Connect priorities and, instead, a broader focus in technical support across AHRQ initiatives. The team worked closely with the AHRQ project team to adjust the scope and manage the remaining budget.

The team completed 29 2-week sprints, or development cycles, throughout the project year. In addition, the team met regularly to consider, select, develop, test, and implement ideas to maintain and enhance CDS Connect, and later in the year, to support intra-agency collaborations.

Among these ideas, defining priorities in patient partnering and applying the latest evidence to CDS artifacts were key efforts. The team also regularly monitored relevant environmental factors (e.g., the potential influence of bias in CDS) to maintain situational awareness and flag potential impacts on the CDS community.

3. Trust Framework

In 2018, the Patient-Centered Clinical Decision Support Learning Network (PCCDS-LN) produced a white paper entitled Recommendations for Building and Maintaining Trust in Clinical Decision Support Knowledge Artifacts. The recommendations in this white paper included a "trust framework" for supporting a trustworthy, knowledge-sharing CDS platform such as CDS Connect. Although CDS Connect has already incorporated several of those recommendations, many of the white paper's recommendations had not yet been implemented (e.g., searching CDS artifacts by knowledge level).

During Year 6, the team continued with improvements to CDS Connect to increase trust in the CDS ecosystem in accordance with the Trust Framework recommendations. The team followed the approach developed in Years 4 and 5 to prioritize the updates to CDS Connect (for additional details on the approach, see the Year 4 report). Guided by the approach initially developed in Year 4, the team solicited feedback during the October 2021 WG meeting on the themes and trust attributes members believed should be the focus for the current project year. The team also realized the benefits stemming from prior years' accomplishments (e.g., listing priorities for rapid prioritization throughout the year, avoiding lags between completion of updates and selection of new updates, engaging the CDS community), with the additional advantage of being able to reduce resources needed for the prioritization process. As with Year 5, this resulted in a

faster prioritization process that was completed with less effort and resulted in more resources being available for other project priorities.
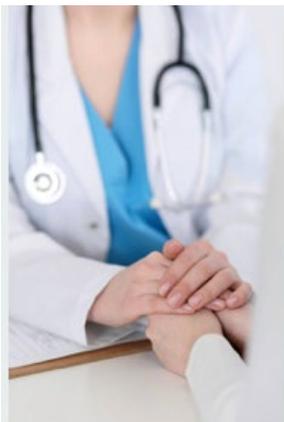
The team identified one primary "must-have" theme for CDS Connect maintenance and update activities to increase trust in the CDS ecosystem—

- Enforce Standards Compliance (CDS Artifacts): Update CDS artifacts already in the Repository to ensure compliance with applicable standards.

Other themes were evenly supported by WG members and included: "Expand the Repository," "Increase Trust," and "Expand the Use of Existing Artifacts."

These themes bounded the scope of priorities for CDS Connect during Year 6 and guided sprint planning and Agile decision making during the first quarter of the project year. Ultimately, the team used the rubric to assess 106 potential updates to CDS Connect. The specific prioritized enhancements included, but were not limited to—

- Support FHIR 4.0.1 (vs. 4.0.0) in the CDS AT for external CQL and CQL download.
- Add ELM XML representations to CDS AT artifact downloads.
- Improve format and layout of downloaded CQL in the CDS AT.
- Improve support for executing CQL 1.5 in CDS AT and open-source tools (CQL Services and CQL Testing Framework).
- Update open-source tools to follow latest standards and best practices (as applicable).
- Update to Drupal 9.

As of the writing of this report, the team completed 26 percent (9 of 26) high-priority "must-have" tasks and 0 percent (0 of 6) of the lower-priority "should-have" tasks, as well as ad hoc items from the backlog of candidate enhancements. The team selected ad hoc items based on late-breaking project needs (e.g., AHRQ collaborations) and staff availability. The completion rate was significantly lower this project year than prior years, which was attributed to a technical direction shift early in the second quarter by AHRQ to refocus efforts on technical support for AHRQ's CDSiC project and enclave migration.

4. Standards Conformance: Repository

The CDS Connect Repository was the platform's first prototype tool. The Repository hosts structured, interoperable CDS expressions— known as CDS artifacts—that support clinician and patient decision making.

The CDS artifacts on the Repository include contributions developed by the team and by trusted third parties. The goal of the Repository is to demonstrate how to more rapidly incorporate evidence-based research into clinical practice through interoperable CDS.

In Year 1 of the development project, the team developed and delivered initial (alpha) and second (beta) versions of the Repository to AHRQ. For more information on Year 1, please see the final report from that year.

Year 2 saw the release of the third (production) version of the Repository, which was the first version publicly accessible on the Internet. For more information on Year 2, please see the final report from that year.

In Year 3 of the project, the team made enhancements to the production version of the Repository. The [final report](#) from that year provides more information.

Year 4 began a new phase that emphasizes long-term maintenance and sustainability of the Repository. During Year 4, the team updated and enhanced the Repository to better align with the most recent CDS-related standards. The enhancements improved the user experience for Repository contributors and consumers.

Year 5 continued the focus on making the Repository a maintainable tool with a focus on the user experience. A sizeable percentage of the team's effort involved revising the CDS artifact data model to better align with standards-based data elements, as well as updating the tooling and component dependencies.

Year 6 focused on completing and deploying the Drupal 9 upgrade and the required system updates for AHRQ to move to the Amazon Web Services (AWS) secure enclave, as well as continuing further development for CPG-on-FHIR, creating a monitoring capability for when artifacts are submitted for review, and addressing various bugs and enhancement requests. The team also updated the website's FAQs, created the Repository User Guide, and updated content project tiles and associated landing pages.

4.1 CDS Artifact Schema Update

Since Year 1 of the project, there have been advances in the healthcare IT standards that can be used to describe CDS. In 2020, the first version of the CPG-on-FHIR IG was released as a standard for trial use (STU). The CPG-on-FHIR was created as part of the [CDC's Adapting Clinical Guidelines for the Digital Age initiative](#). Its purpose is to support "the development of standards-based computable representations of the content of clinical care guidelines" (http://build.fhir.org/ig/HL7/cqf-recommendations/index.html#intro).

Through coordination with the WG and CDS community during Year 4, the team determined that CDS Connect should align its tools with CPG-on-FHIR, where feasible.
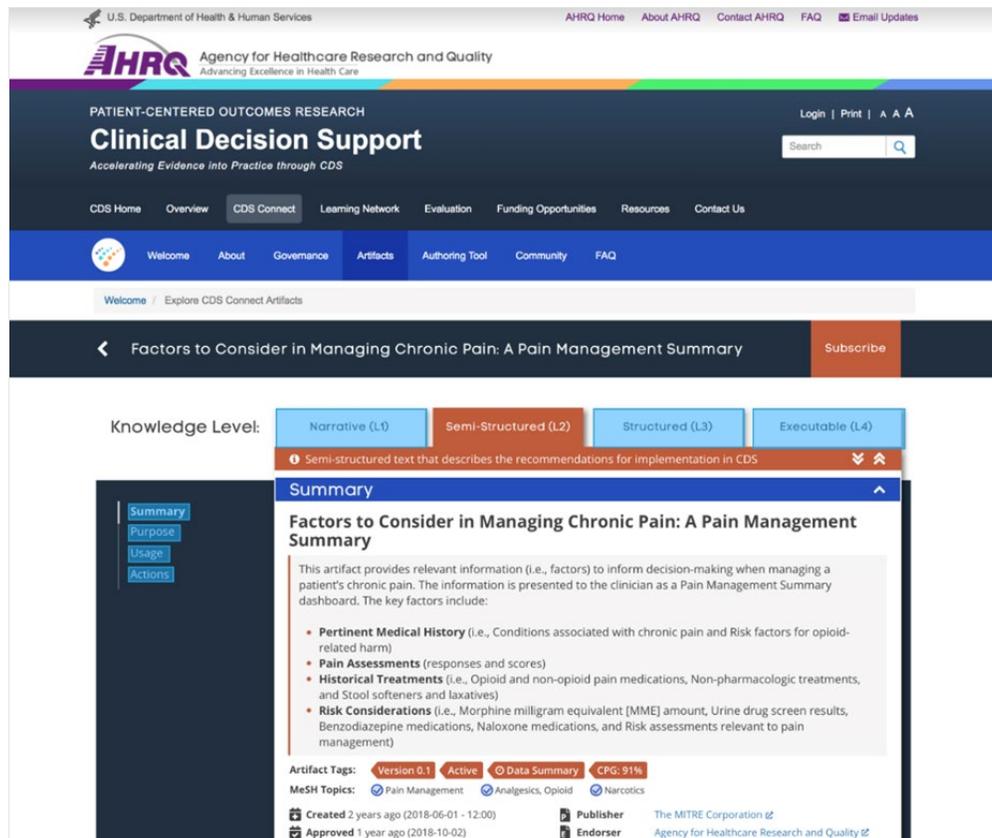
Figure 2. Image of Initial Design Mockup for New CDS Artifact Schema

During previous contract year work, the team developed initial prototypes of the CPG-on-FHIR backend and user interface (see Figure 2). At the beginning of contract Year 6, the team revised prototype implementations by applying Drupal best practices for managing data fields and user interface elements.

Due to technical shift, the team temporarily paused CPG-on-FHIR work to accommodate priority tasking. This work is under consideration with AHRQ to continue with any future CDS Connect projects.

4.2 Simplified Development and Deployment Process

Previously, in Year 5, the team moved to using the deployment Git Repository as the common repository for both development and deployment. This change resulted in a more streamlined process for deploying new features, developing fixes for identified problems, and implementing patches.

In Year 6, the team built upon the work in Year 5 on moving to a single Git Repository to improve the team's processes for managing code changes and enhancements. The team used long running development branches that were aligned with the additional Acquia applications, Drupal 9, and CPG-on-FHIR. This change further simplified the development process and allowed development of these tasks to proceed without impeding production support.

This approach also helped the team prepare for the move from Acquia Dev Desktop to Acquia Cloud IDE; in Year 6 the team received licenses for two individuals.

4.3 Drupal 9 Upgrade

The team set up an additional Acquia application for testing and evaluating the Drupal 9 upgrade. This application provided additional development and testing environments that the team utilized solely for the Drupal 9 upgrade, while also utilizing the main development and staging environments to support security patching, issue troubleshooting, feature enhancements, and general development.

The move to Drupal 9 required the team to review and update direct and transitive dependencies for Drupal 9 compatibility. The team used the "upgrade status" plugin for repeated passes to identify libraries that needed updating to compatible versions. The team also had to review custom CDS Connect code for use of deprecated or removed application program interface (API) calls. Additionally, the team addressed the required updates to database and entity references changes.

After the upgraded environment was available on local development environments and in the Acquia cloud development environment, the team performed multiple rounds of testing to simulate a production upgrade.

To perform the production upgrade, the team undertook work to upgrade the existing Drupal 8 production environment. While this path was an in-place upgrade and required more work at the time of the upgrade, it also meant that DNS and reverse proxy pointers would not have to be adjusted, giving the team more control over the upgrade process.

In the months after the upgrade was pushed to production, the team performed several follow-up tasks and addressed unexpected bugs due to upstream component changes for Drupal 9 or instances of CDS Connect custom code requiring additional changes due to deprecated APIs or changes in dependency injection named identifiers.

4.3.1 Improving Memory Management and Performance

After the Drupal 9 upgrade was completed, the team identified performance issues with certain aspects of the Drupal site. The first issue the team found was regarding the functionality of the Medical Subject Heading (MeSH) taxonomy browsing section within the artifact discovery page. The team discovered that this issue was related to memory limitations on the system and the shared hosting environment.

The second issue the team encountered involved aspects of the system—which were not visible to users—that were also attributed to memory issues. The team approached these problems on two fronts: AHRQ upgraded the Acquia contract to include additional memory; simultaneously, the team also pursued development changes to use memory space more judiciously for key page loads, API calls, hooks, and command extensions.

In re-enabling the MeSH taxonomy browsing, the team discovered a secondary issue where event attendees were not properly being registered on the event pages. The team addressed this error by updating the JavaScript library "Once" and associated HTML code that triggers event handler registration upon dynamic HTML elements being added. At the time of the of this report, this solution is undergoing final implementation and testing before being released to production.

4.4 Usability Improvements

In Year 6, the team started planning for incorporating a Repository User Guide into the online help and documentation system. The initial content, drafted as a Word document, would be transferred into a Drupal-managed content format via the Drupal Books module. The team and AHRQ reviewed the Repository User Guide content and images, then transferred the information into an HTML format. Currently, the team has uploaded the draft into the development environment for testing and further iteration and integration.

4.4.1 Secure Enclave Updates

The team designed and tested several changes in support of the migration of AHRQ infrastructure resources to the new secure enclave AWS environment. The most effortful of these changes included moving the Lightweight Directory Access Protocol (LDAP) directory server that is used to authenticate user access and to maintain group membership.

The team identified the outgoing IP addresses used for requests from the Drupal server to the secure enclave directory server to adjust the secure enclave firewall rules.

The Acquia Drupal environment required testing to ensure that the Acquia-managed servers were connected to the secure enclave directory server. Additionally, the team replaced the previous cleartext communication with a Transport Layer Security (TLS) encrypted communication channel used for LDAP over Secure Sockets Layer (LDAPS) communication and using a private certificate authority-issued certificate. This private Certificate Authority (CA) in turn required the trust chain to be manually updated and tested using documentation provided through an Acquia support ticket. At the time of the Final Report, this task is still undergoing configuration and testing in advance of deployment that is anticipated in a month.

4.4.2 General System Improvements

The team made general system improvements to the Repository during Year 6.

The team updated the Repository to ensure that security patches and bug fixes released for Drupal[3] were applied in a timely manner. The Repository uses Drupal Version 9, which operates on a semiannual minor version release cycle. Because each minor release for Drupal receives security support for 1 year, it is important that the Repository stay current. As of the date of this report, the Repository is on the long-term support release for Drupal 9.

The cloud environments continued to use PHP 7.4 during Year 6. To stay current with support, the upgrade from PHP 7 to PHP 8 is planned for Q2 or Q3 2022, as PHP 7.x is reaching its end-of-life support deadline on October 3, 2022.

4.5 Additional Updates

As of the writing of this report, the period of performance for Year 6 is not yet complete. In the remaining months of Year 6, the team aims to additionally complete the following enhancements:

- Making available a Repository User Guide for site visitors and artifact authors.
- Posting patient-partnering materials to the website.
- Updating the website content and functionality to reflect the conclusion of the WG.
- Developing and deploying home page tiles announcing other AHRQ projects of interest to the greater CDS community.
- Finishing development of and deploying a notification capability for alerting CDS Connect administrators of Artifacts that have been submitted for review.
- Improving memory performance and response time of the MeSH taxonomy browsing capability on the artifact discovery page.

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[3] The Repository is based on Drupal as the underlying content management system.

5. Standards Conformance: Authoring Tool

In Year 1 of the CDS Connect project, the team designed and built the CDS Authoring Tool, a user-friendly web application for creating standards-based CDS logic using Health Level Seven (HL7) CQL and HL7 FHIR.

The team spent Years 2 through 5 improving the CDS Authoring Tool based on project requirements and user feedback. By the end of Year 5, the CDS Authoring Tool supported the following features:

- Logging in with a user account to manage a personal set of CDS logic artifacts.
- Authoring CDS logic using inclusion and exclusion criteria, sub-populations, and conditional recommendations.
- Building custom modifiers using an advanced query builder interface.
- Integrating with the National Library of Medicine's Value Set Authority Center (VSAC) to find and select value sets as well as to validate individual codes.
- Defining "base elements" that can be specified once and used multiple times throughout the CDS artifact.
- Importing externally authored CQL to support constructs not expressible in the CDS Authoring Tool.
- Specifying run-time parameters to allow implementers to change the behavior of CQL logic at run-time.
- Annotating CDS elements with human-readable comments.
- Providing artifact metadata that aligns with the FHIR Clinical Guidelines specification.

- Testing authored logic using synthetic data to verify its correctness.
- Exporting valid CQL using the FHIR Draft STU 2, FHIR STU 3, or FHIR Release 4 data models.

The CDS Authoring Tool is provided under an open-source Apache 2.0 license on GitHub and hosted in an AHRQ production environment. Going into Year 6 (September 2021), the CDS Authoring Tool had 609 registered users. As of the writing of this report (May 2022), the CDS Authoring Tool had 781 registered users.

In Year 6, several organizations continued the extension and reuse of the CDS Authoring Tool, including:

- An AHRQ grantee's continued development of a prototype drug-drug interaction alerting system as an extension of the CDS Authoring Tool open-source code.
- Faculty at a medical school used the CDS Authoring Tool in their own CDS authoring platform along with several other open-source CDS tools.

During Year 6, the team focused on aligning with current health IT standards, presenting terms and conditions for using the tool, improving usability of the tool, implementing capabilities to support migration to the AHRQ Enclave, and supporting easier maintenance and re-use of the open-source code.

5.1 FHIR 4.0.1

HL7 CQL supports two different variants of FHIR Release 4 (R4): version 4.0.0 and version 4.0.1. While these variants are nearly identical, systems capable of executing CQL may support one or the other.

The CDS Authoring Tool initially provided support only for FHIR R4 4.0.0. In Year 6, the team implemented additional support for FHIR R4 4.0.1. This enables users to upload external CQL that uses FHIR 4.0.1, test their R4-compliant artifacts using FHIR 4.0.1, and download CQL leveraging the FHIR 4.0.1 data model. In many cases, users can choose between FHIR 4.0.0 and FHIR 4.0.1 when downloading their artifact CQL. Figure 3 depicts the various FHIR versions that may be available to an author when downloading an artifact.

Figure 3. Choosing to Download an Artifact With FHIR 4.0.1

5.2 Expression Logical Model XML Downloads

The CQL specification defines the Expression Logical Model (ELM) for representing CQL logic in a format that is easier for machines to process. ELM can be represented using JavaScript Object Notation (JSON) or Extensible Markup Language (XML). Different CQL processors may prefer either the JSON or XML format.

Prior to Year 6, CDS Authoring Tool users could download their artifacts as CQL and ELM JSON. In Year 6, the team extended the download capability to also include the ELM XML files. This allows the CDS artifact to be more easily integrated into systems that prefer the XML variant of ELM. Figure 4 demonstrates the contents of an artifact download containing the new ELM XML files.
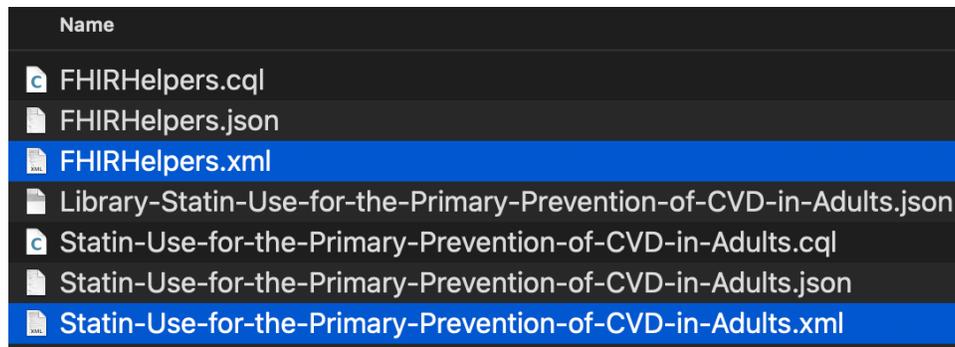
Name
FHIRHelpers.cql
FHIRHelpers.json
FHIRHelpers.xml
Library-Statin-Use-for-the-Primary-Prevention-of-CVD-in-Adults.json
Statin-Use-for-the-Primary-Prevention-of-CVD-in-Adults.cql
Statin-Use-for-the-Primary-Prevention-of-CVD-in-Adults.json
Statin-Use-for-the-Primary-Prevention-of-CVD-in-Adults.xml

Figure 4. CDS Authoring Tool Artifact Download With ELM XML files

5.3 Terms and Conditions

The CDS Connect Repository requires users to agree to terms and conditions of use when signing up for an account. In Year 6, the CDS Authoring Tool added terms and conditions of use that are like those in the Repository. The terms and conditions provide guidance on the use of the CDS Authoring Tool, including governance, assurance, and ownership of the artifacts created in the tool. Figure 5 depicts the terms and conditions prompt.

To author and edit CDS artifacts, users must agree to the terms and conditions. All new users of the CDS Authoring Tool will be prompted to read and accept the terms and conditions when they first log in. All existing users will be prompted to read and accept the terms and conditions the first time they visit the CDS Authoring Tool after the terms and conditions were released.
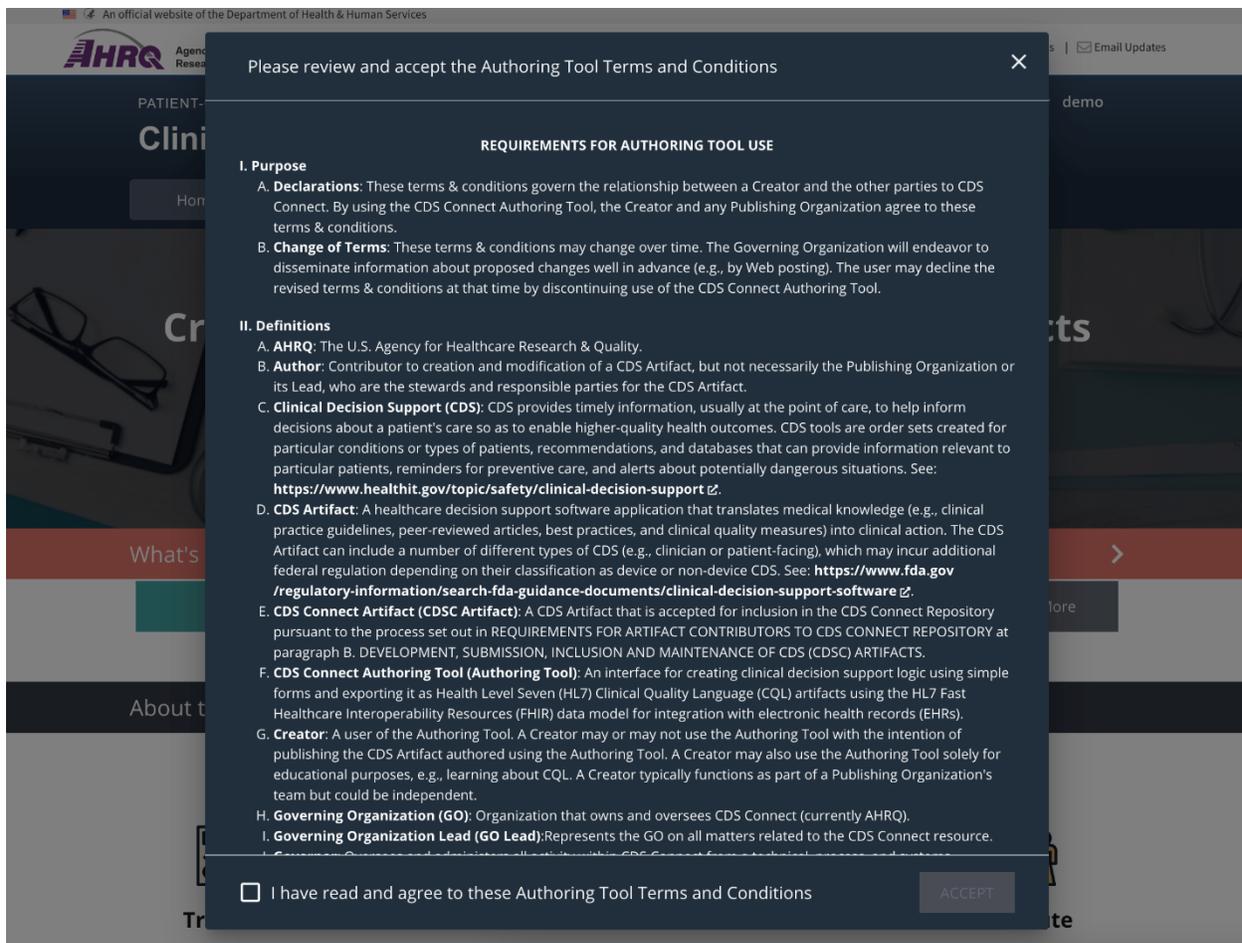
Figure 5. CDS Authoring Tool Terms and Conditions Prompt

5.4 Secure Communication Protocols

In Year 6, the team updated the CDS Authoring Tool to support encrypted connections to and from the application. As part of this effort, the team added support for the following:

- Incoming connections to the API server using Hypertext Transfer Protocol Secure (HTTPS).
- Incoming connections to the frontend web server using HTTPS.
- Outgoing connections to a LDAP server using LDAPS.

CDS Authoring Tool providers can configure these capabilities, including support for custom security certificates, via the CDS Authoring Tool configuration file or specially defined environment variables.

5.5 Improved Docker Builds

The CDS Authoring Tool is typically built and deployed using a platform called Docker. Using Docker as a build platform allows for consistent testing and deployment across development, staging, and production environments.

In Year 6, the team updated the CDS Authoring Tool Docker scripts to support multistage builds with integrated unit testing. As a result, automated build servers can build and test the CDS Authoring Tool more efficiently. In addition, the improved build resulted in a significant decrease in the file size of the deployment package, saving bandwidth and storage costs.

5.6 Usability

In Year 6, the team continued to improve usability of the CDS Authoring Tool. Many components of the application received a visual refresh as the team adopted modern component libraries such as Material-UI, a React framework that follows material design principles. In Figure 6, the lefthand side shows the Recommendations page as it was at the start of Year 6, and the righthand side shows the visual and organizational updates the team made to this page.
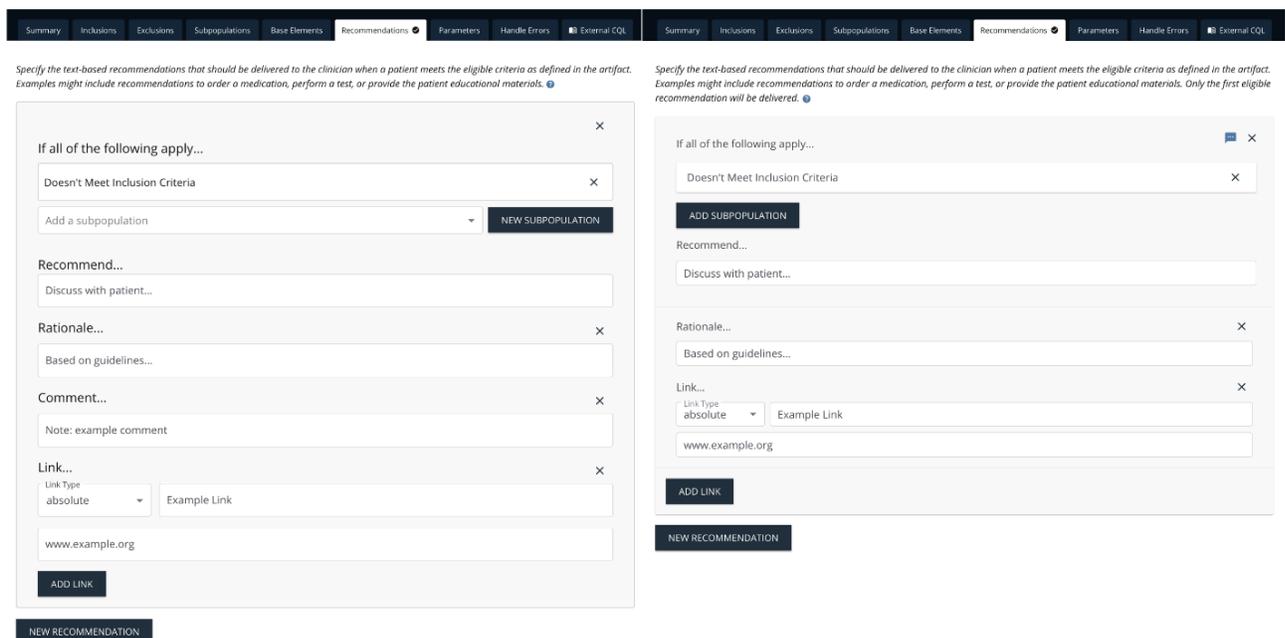

Figure 6. **Recommendations Page Usability Updates**

5.7 Maintainability

Over the past 6 years, open-source technologies for building dynamic web applications have continued to improve. During that time, requirements for the CDS Authoring Tool have become clearer, and the team has gained knowledge and experience. In Year 6, the team focused on applying these new technologies, lessons learned, and best practices to the CDS Authoring Tool code base to improve its quality, efficiency, maintainability, and ease of reuse. This significant effort included activities such as:

- Adding, removing, and updating dependency libraries as appropriate.
- Switching homegrown components to use Material-UI.
- Leveraging React Hooks to simplify component logic, lifecycles, and state management.
- Modularizing components for reuse across the application and in other applications.
- Defining styles local to the components where they are used.
- Applying consistent coding practices throughout the code base.

As a result, teams working on the CDS Authoring Tool can onboard new developers more quickly, maintain the code more easily, and implement new features more efficiently. In addition, external teams can more easily extend the CDS Authoring Tool or reuse components from the CDS Authoring Tool in their own applications.

5.8 Additional Updates

As of the writing of this report, the period of performance for Year 6 is not yet complete. In the remaining months of Year 6, the team hopes to additionally complete the following enhancements:

- Improve the formatting and organization of downloaded CQL logic with the goal of enhancing readability.
- Update the underlying CQL execution engine to align more closely with the CQL 1.5 specification.
- Extend the query builder to support "reshaping" the query results that are returned as part of the expression.

In addition, the team will continue to improve usability, maintainability, and reusability of the CDS Authoring Tool.

6. Standards Conformance: Open-Source Tools

The CDS Connect project has developed other open-source tools over previous years. These include CQL Services, the CQL Testing Framework, and the Pain Management Summary Application.

6.1 CQL Services and Enhancements

CQL Services is an open-source application that enables users to expose CQL-authored logic over custom and standards-based web services. In Year 6, the team continued to maintain CQL Services by providing bug fixes and software updates as needed. These updates included enhancements to the underlying CQL execution engine to improve support for CQL 1.5. Figure 7 depicts the CDS Hooks Sandbox interface.

Figure 7. Example CQL Services Response in the CDS Hooks Sandbox

6.2 CQL Testing Framework and Enhancements

The CQL Testing Framework is an open-source library that allows developers to create and execute tests cases for CQL libraries. Unlike the testing feature in the CDS Authoring Tool, the CQL Testing Framework can work with any CQL (wherever it was developed) and can test actual against expected results.

In Year 6, the team continued to maintain the CQL Testing Framework by providing bug fixes and software updates as needed. These updates included enhancements to the underlying CQL execution engine to improve support for CQL 1.5.

6.3 Pain Management Summary Application and Enhancements

The Pain Management Summary Application is a Substitutable Medical Applications, Reusable Technologies (SMART) on FHIR application that allows clinicians and patients to view all individual patient data that might be relevant to managing that patient's pain. The Pain Management Summary application was developed and piloted in Year 2 of CDS Connect (see Figure 8). In Year 6, the team continued to maintain the Pain Management Summary Application by providing bug fixes and software updates as needed. In addition, the team updated the embedded CQL logic to align with the most recent version of the Factors to Consider in Managing Chronic Pain artifact on CDS Connect.

Figure 8. The Pain Management Summary Application

7. Standards Conformance: CDS Artifacts

The team reviewed all MITRE-authored CDS Artifacts (Table 1). The team's criteria for considering updates included a review of new relevant professional guidelines or research evidence, value sets, updated FHIR and CQL standards, documentation, and metadata, as described in the FAQs.

Table 1. Annual Review and Update of CDS Connect Project Team Authored CDS Artifacts

CDS Artifacts[4]	Evidence Updates	Value Set Updates	Logic Updates	Metadata Updates
Abnormal Blood Glucose and Type 2 Diabetes Mellitus: Part One, Screening	Yes	Yes	Yes	Yes
Abnormal Blood Glucose and Type 2 Diabetes Mellitus: Part Two, Counseling	Yes	Yes	Yes	Yes
Aspirin Therapy for Primary Prevention of CVD and Colorectal Cancer	Postponed until next year	N/A	Postponed until next year	Yes
CMS's Million Hearts® Model Longitudinal ASCVD Risk Assessment Tool for Baseline 10-Year ASCVD Risk	Retired	N/A	N/A	Yes
CMS's Million Hearts® Model Longitudinal ASCVD Risk Assessment Tool for Shared Decision Making	Retired	N/A	N/A	Yes
CMS's Million Hearts® Model Longitudinal ASCVD Risk Assessment Tool for Updated 10-Year ASCVD Risk	Retired	N/A	N/A	Yes
Factors to Consider in Managing Chronic Pain: A Pain Management Summary	No	Yes	Yes	Yes
Healthy Diet and Physical Activity for CVD Prevention in Adults With Cardiovascular Risk Factors	No	Yes	Yes	Yes
Statin Therapy for the Prevention and Treatment of Cardiovascular Disease (CVD) eCQM	Yes	Yes	Yes	Yes
Statin Use for the Primary Prevention of CVD in Adults: Clinician-Facing CDS Intervention	No	Yes	Yes	Yes
Statin Use for the Primary Prevention of CVD in Adults: Patient-Facing CDS Intervention	No	Yes	Yes	Yes

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4 Occupational Factors Impacting Diabetes is under consideration for update or retirement in coordination with the National Institute for Occupational Safety and Health.

In Year 6, the team's subject matter experts relied on the step-by-step process (including a one-page summary infographic and FAQ "How do I maintain my contributed CDS artifact?" developed last year) for updating each component of a CDS artifact. Notably, the update for the Aspirin Therapy for Primary Prevention of CVD and Colorectal Cancer was postponed until the next year, given the significant evidence change was published after Year 6 updates were made to the CDS Artifacts and the resultant need to further consult with subject matter experts on how to reflect the new guidance in the CDS. The project team did alter the status of the CDS artifact in the Repository and post a warning to notify the community about the evidence change and need for update.

The team created and delivered a presentation to the WG on March 17, 2022, to discuss versioning of CDS artifacts as they are updated. Members of the WG provided pertinent and helpful suggestions, which the team implemented to improve the update process.

The team updated the CQL for all CDS Connect project-authored CDS artifacts with existing CQL representations. These CQL updates include the following changes:

- New library names based on guidance from the FHIR Clinical Guidelines specification.
- Use of quoted identifiers and descriptive argument names based on guidance from the FHIR Clinical Guidelines specification.
- Organizational and logic updates to follow best practices and enhance reuse of logic.
- Logic updates based on evidence updates (where applicable).
- Terminology updates based on terminology review (where applicable).

The team updated all CQL libraries to be designated as version 2.0.0, as according with semantic versioning practice changing the library names is considered a "breaking" change.

The team provided an editorial review of all IGs to improve clarity of writing and standardize the placement and content of text commonly used across multiple artifacts. The team has also ensured that the IGs are 508 compliant.

Finally, in Year 6, the team created new value sets in response to new evidence and evaluated existing value sets for new codes, alternative value sets, and opportunities to make intensional.

As in earlier project years, the team worked with the CDS community, including the WG, during Year 6 to review and update existing CDS artifacts contributed to the Repository by groups other than MITRE. This effort is a major accomplishment in the team's ongoing work to maintain trust in CDS Connect.

Upon request, the team worked with CDS artifact authors to review and update their CDS artifacts (i.e., Preferred Therapy Recommendation for Adult Asthmatic Step 1-to-2 Transition, Alcohol Screening Using the USAUDIT (Alcohol Use Disorders Identification Test, Adapted for Use in the United States), including a review of their evidence, metadata, value sets, and documentation. Related to the implementation of CDS Connect Governance, the team is preparing an article for invited submission to a peer-reviewed journal.

The team also worked with contributors providing new CDS artifacts to the Repository (e.g., RTI, MedStar, and TISTA Science and Technology Corporation). Contributors included other Federal agencies, existing contributors, and individuals within medical systems. Activities included providing information to those asking to learn more about the contribution process, creating accounts, advising interested parties on how to use the Repository, and reviewing submitted material ahead of publishing it to the CDS Connect Repository.

Finally, the Project and Authoring Tool Leads participated in the monthly Value Set WG to provide feedback on the use of the VSAC, as well as provide a use case for how CDS uses the value sets.

7.1 Work Group

The WG serves a critical function by providing diverse subject matter expertise to aid in the prioritization of CDS Connect development activities. The WG has engaged throughout key project phases, from consideration of high-level desired outcomes for CDS Connect to selection of optimal approaches for maintaining and updating CDS Connect. In Year 6, the team worked with the WG moderator to maintain the WG, while increasing the diversity of participation and presentation, including—but not limited to—facilitating monthly virtual meetings, developing, and inviting content, summarizing meetings through publicly available notes and presentation materials, and responding to questions from new and existing members.

The team works with the WG's 144-plus members to promote engagement from the diverse members, whose expertise ranges from clinicians to coders. The team maintained the prior year's practice of conducting a shorter, 60-minute meeting and highlighting specific feedback requested from presenters or participants. During the meetings, the team focused on specific discussion questions with clear objectives and used the chat feature to invite greater participation. Attendance and participation remained consistent over the year.

The WG met seven times during the reporting period (September 2021–August 2022). The WG meeting was canceled in November and January based on members' limited availability and preference. The WG meeting was also cancelled in May, July, and August, as efforts shifted to concluding the project and resolving the WG. WG members expressed interest in continuing to engage with the community, and the team has provided additional information and resources to maintain involvement.

Meetings averaged an attendance of 36 WG member per month, and overall attendance ranged from 31 to 39 attendees. Four guest speakers participated in roundtable discussions on their patient-partnering experiences, and one external speaker presented their research that involved partnering through coproduction. Those sessions included:

- "One More Step" in Patient Partnering/AHRQ Grantee Roundtable.
- Project ACTIVATE (Advancing Coordinated and Timely InterVentions, Awareness, Training, and Education) Overview.
- Roundtable and Discussion on Patient-Partnering Experience.

The team presented three topics to gather feedback and promote discussion among WG members. These topics included:

- Key updates from the previous project year.
- Priorities for the current project year.
- Versioning of CDS artifacts.

With the overall shift in technical direction, the team, in partnership with AHRQ, made the decision to conclude the WG. A final WG meeting reviewed the efforts and accomplishments of the WG over the past 6 years and allowed AHRQ to introduce the WG members to the upcoming CDS Connect transition opportunity to a public-private partnership.

8. Outreach

During Year 6, the team's outreach efforts concentrated on increasing the use of CDS Connect tools by the CDS community. Activities included:

- Demonstrating CDS Connect tools and functionalities, including at national research conferences.
- Facilitating and participating in meetings between AHRQ and stakeholder groups (e.g., potential sustainer organizations, Federal partners, standards meetings such as HL7 and VSAC, and grantees).
- Tracking stakeholder recommendations for consideration in future sprints.
- Building awareness and use of CDS Connect using varied platforms (e.g., email notifications, peer-reviewed publication).

In-person conference attendance continued to be impacted by the COVID-19 pandemic. Therefore, in the first half of Year 6, the team continued to seek virtual and varied media for outreach opportunities. The AHRQ CDS Connect/CEPI Evidence Discovery And Retrieval (CEDAR) Showcase, held in September 2021, was one such outreach event. The second half of the year was focused on the technical direction shift and did not include seeking additional conference attendance.

Ultimately, the team's alternative outreach plan succeeded in meeting project requirements and providing continued engagement with the CDS community during the continuation of an unprecedented time. The alternative plan allowed the team to have greater resources for development efforts and avoid delays in development progress that often coincide with team travel and multiday conference participation.

8.1 CDS Community

The team regularly engages with CDS community stakeholders beyond the WG. The regular engagements included:

- Those with existing contributors (e.g., HLN Consulting, LLC).
- Federal partners (CMS [including the Value Set WG], CDC, and National Institute of Occupational Safety and Health).
- Other CDS meetings (e.g., showcasing CDS Connect efforts and the Authoring Tool to groups upon request).

This project year, under AHRQ's guidance, the team also had extensive collaborations with the CDSiC and enclave migration projects. These efforts included regular meetings and extensive development work to benefit the overall CDS community. The team also continued to collaborate with other AHRQ projects, including AHRQ's CEDAR Project's interactions with the Repository and CDS website.

To provide a patient perspective, Danny van Leeuwen (HealthHats) continued to serve as a patient/caregiver activist and advocate, working closely with CDS Connect. He participated regularly in the CDS Connect WG discussions and provided critical input on public-facing outputs (e.g., Patient-Partnering Panel postings and materials). In addition, Mr. van Leeuwen

facilitated the patient-partnering roundtable WG meeting with AHRQ-funded researchers and was a panelist in the patient-engagement WG session.

Building on the Patient-Partnering Panel work of the prior year, the team provided perspectives from outside the immediate community by having Dr. Katherine Kim (MITRE) present on coproduction methods used in her Accountability, Coordination, and Telehealth in the Valley to Achieve Transformation and Equity (ACTIVATE) Project and Dr. Amy Price (Stanford) discussed her perspective with patient partnering. Their examples, the discussion it fostered, and additional Patient-Partnering Panel materials continued to encourage CDS community members to incorporate patient partnering in their own CDS development activities.

8.2 Conferences

The team attended a conference in Year 6, with the goal of identifying current trends and issues related to patient-centered CDS, gauging attendees' level of awareness and use of CDS Connect, and promoting the use of CDS Connect tools.

8.2.1 American Medical Informatics Association 2021 Annual Symposium

The American Medical Informatics Association (AMIA) Annual Symposium provides a venue for clinical informatics researchers and implementers to share insights with one another.

The AMIA 2021 Annual Symposium was held October 30–November 3, 2021, in San Diego, CA. Two members of the team attended the conference, both of whom copresented in separate 3-hour CDS workshops.

During the AMIA session "W01: A review of fundamentals on using Clinical Quality Language (CQL) for Clinical Decision Support (CDS) and detailed use cases with interactive Q&A," the team presented an overview of CDS Connect Repository and Authoring Tool capabilities as a part of a panel discussion with other CDS community members from the Mayo clinic, the University of Utah, the University of Washington, Dynamic Content Group, and Clinical Cloud Solutions. This described how the CDS Connect capabilities allow community members to author and share CDS artifacts and work with other CDS and CQL tooling.

The "W13: Open-Source and Interoperable Approaches for Clinical Decision Support" workshop was proposed, planned, and performed by several individuals from academia, government, and industry. This workshop was based on a similar workshop from the previous year, but introduced improvements based on participant feedback and the ability to meet in person. To introduce the workshop, a member of the CDS Connect team provided an overview of current CDS standards, technologies, and tools. Participants in the workshop then worked with a cloud-based "CDS-Sandbox," provided by the University of Colorado, to create and test an example CDS artifact. These participants used two CDS Connect tools: the CDS Authoring Tool and CQL Services. Over 30 people participated in the workshop, many of whom reported that they found the workshop useful and informative.

The W13 workshop panelists also submitted a manuscript titled "Playing in the Clinical Decision Support Sandbox: Tools and Training for All" for publication in the JAMIA Open journal. This manuscript describes the CDS-Sandbox, its use in the AMIA workshop, participants' experience of the workshop, and the need for more open tools and standards in the CDS community. As of the writing of this report, the manuscript is under review.

8.3 CDS Connect Site and GitHub Metrics

Year 6 of CDS Connect marked the second year in the project of having regular site metrics.

On average, users most often visited the CDS Connect landing page, generating 383 unique views each month (consistent with last year's 370 views). Users visited the Repository the second most often (174 unique views each month). CDS artifact files were the most downloaded content, with approximately 19 downloads each month (consistent with last year's 21 downloads per month).

CDS Connect shares open-source code on GitHub. Figure 9and Figure 10 display page views and clones, respectively, from September 2021 until August 2022. On GitHub, a "clone" represents when a user has downloaded the open-source code to their system for local use and modification.
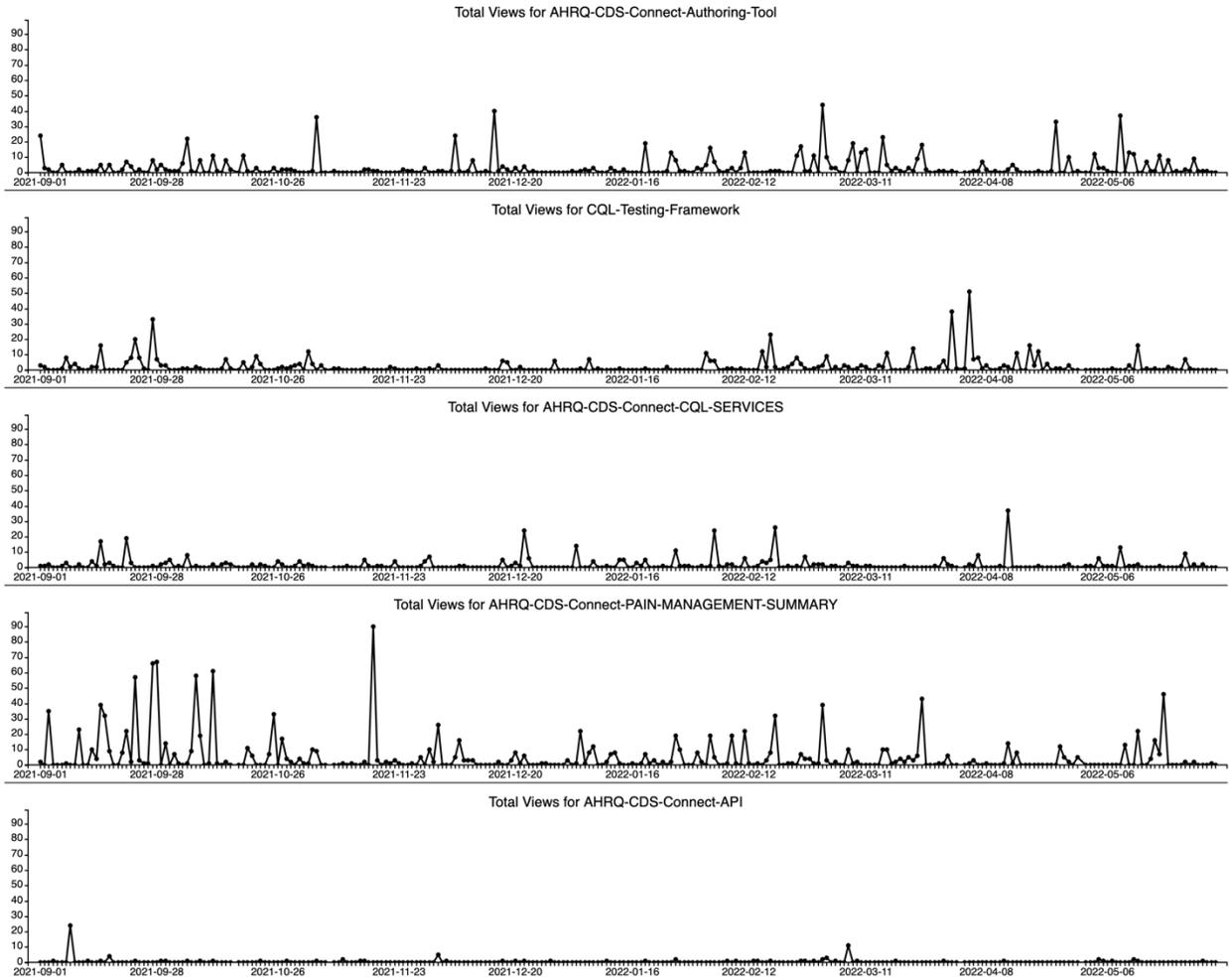
**Figure 9. Total Views for AHRQ-CDS GitHub Repositories**
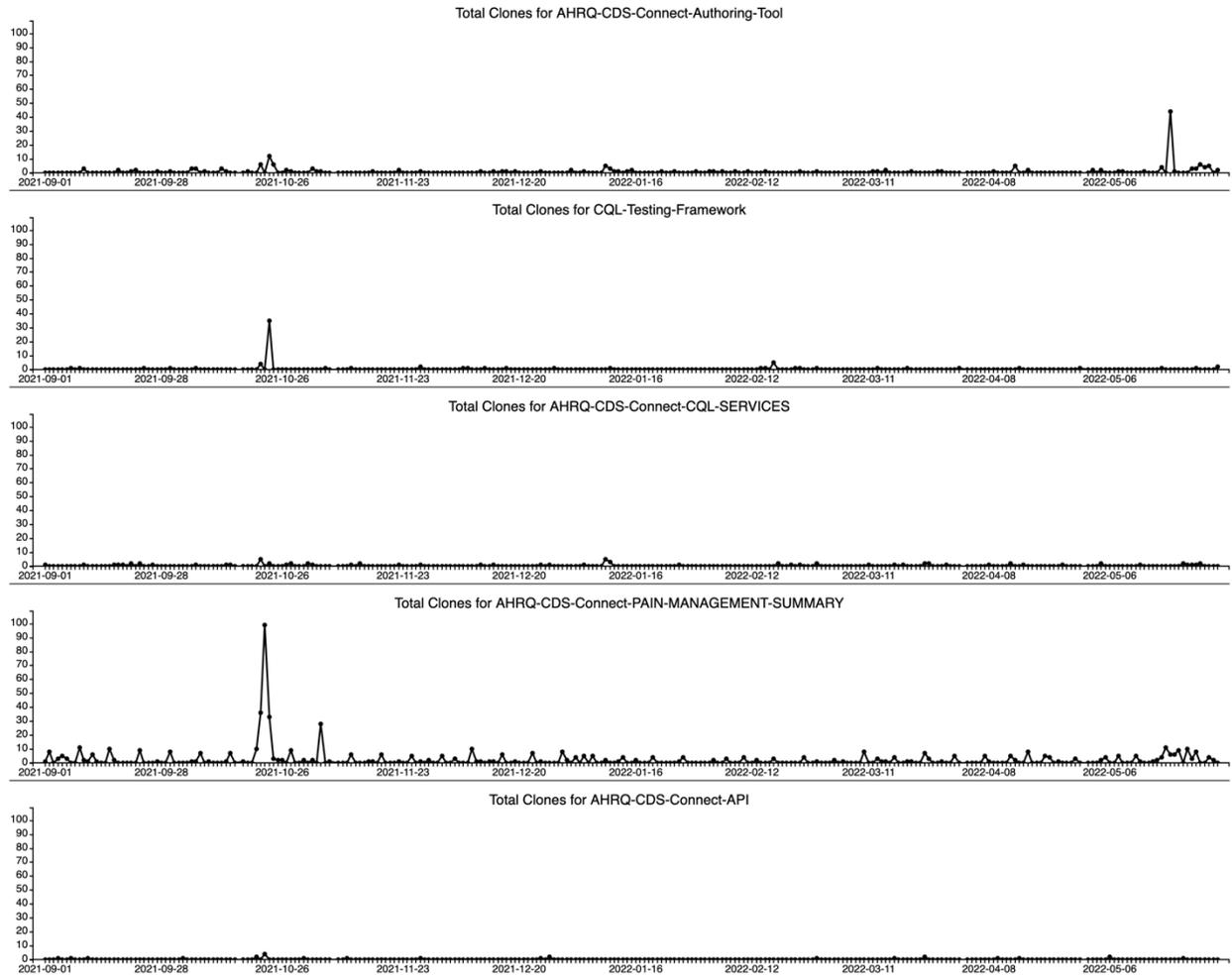
Figure 10. Total Clones for AHRQ-CDS GitHub Repositories
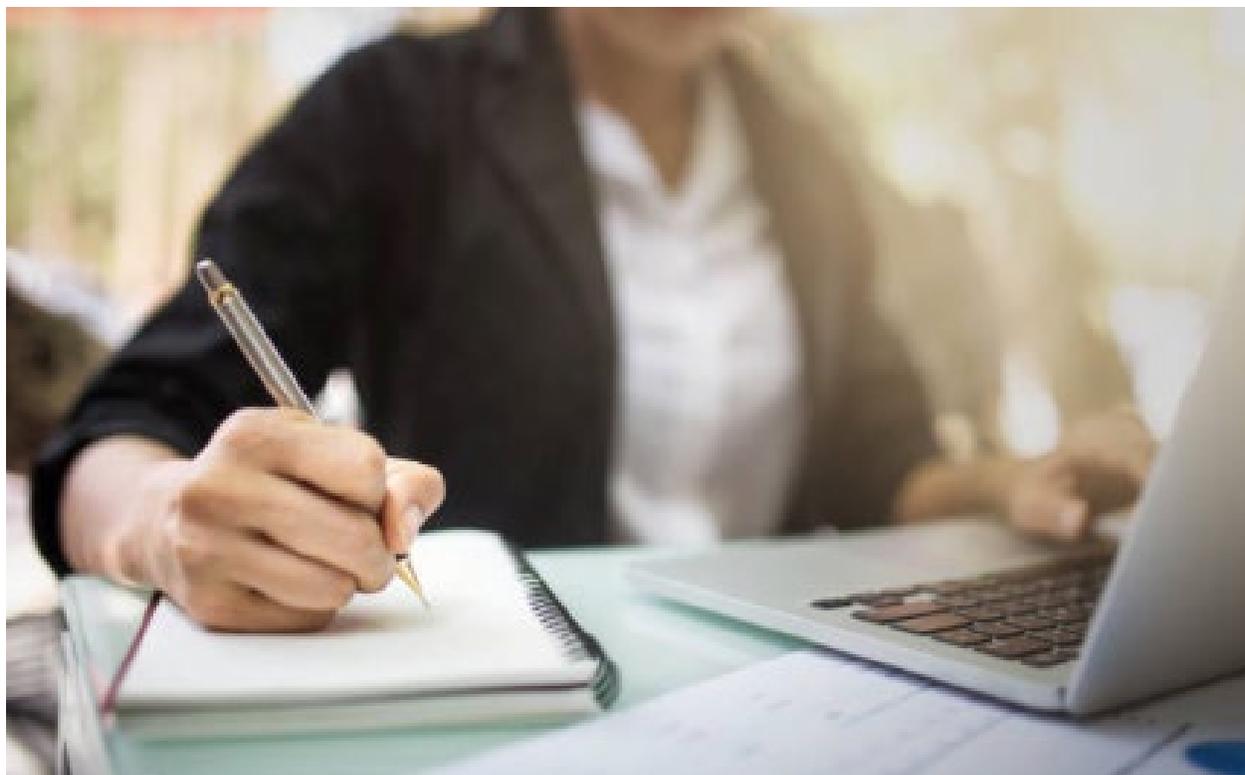
9. Lessons Learned and Recommendations

The following observations from the team's Year 6 activities may be useful for CDS projects and the broader CDS community:

9.1 Enforcing Standards Compliance

- Enhance CDS artifacts with the latest evidence and standards, as available. Incorporating the latest evidence and standards into the CDS artifacts affords the greatest value to the user community (i.e., CDS that reduces the translation time between research and practice). This year, late breaking evidence updates were incorporated into MITRE-AHRQ-authored CDS by the AHRQ project team, given converging timelines and alternate priorities.
- Recommendation: As evidence and standards evolve ever more rapidly, it will be helpful to consider processes or systems to alert of future changes and predict said impact. Maintenance of CDS is comparable to maintenance of quality measures and incurs the same challenges to resource availability. To ensure the feasibility of maintenance, it will be critical to have review and update efforts coincide with the release of the most impactful evidence and standards changes of the cycle. The team will continue to seek opportunities to create a streamlined feedback loop.

9.2   Expanding Use

- Engage with undergraduate and graduate institutions. The use of CDS Connect in institutions of higher learning has grown organically. As of the writing of this report, three cohorts from various institutions had appeared to use CDS Connect as part of their coursework.
- Recommendation: Given the agile nature of CDS Connect and its cyclical development process, expanding efforts within other learning communities might be an optimal environment for supporting CDS Connect, while also allowing for innovations to occur. In the next project year, the team will consider the options to formally engage with the college and university community.

9.3   Continuing Patient-Partnering Efforts

- This year, within the WG, the team pursued a "One More Step" campaign with patient partnering. Building on the Patient-Partnering Panel, the WG invited speakers to explore and continue to shape patient-partnering resources, as well as create a prioritized list of actions that may benefit the CDS community.
- Recommendation: The team intends to post the developed resources to the CDS Connect website. In the coming project year, it will be beneficial to use the resources and consider alternative outreach options to promote sharing the information in the broader CDS community, particularly given the end to the WG.

Overall, lessons learned applicable to the broader CDS community include themes of use and standards of CDS artifacts. The CDS community continued to support the selection of priorities when there are more options available than resources to perform them all. The team actively seeks insights into the most useful aspects of CDS Connect, as the project heads into its next phase after completion of the Maintenance and Update phase this project year. The team looks toward pursuing development activities originally prioritized for this project year that impact the Repository, CDS Authoring Tool, and Site, while seeking opportunities to promote the use and impact of CDS Connect in the broader community.

Appendix A. Acronym List

Term	Definition
ACTIVATE	Advancing Coordinated and Timely InterVentions, Awareness, Training, and Education
AHRQ	Agency for Healthcare Research and Quality
AMIA	American Medical Informatics Association
API	Application Programming Interface
AT	Authoring Tool
AWS	Amazon Web Services
CA	Certificate Authority
CDC	Centers for Disease Control and Prevention
CDS	Clinical Decision Support
CDSiC	Clinical Decision Support Innovation Collaborative
CEDAR	CEPI Evidence Discovery And Retrieval
CEPI	Center for Evidence and Practice Improvement
CMS	Centers for Medicare & Medicaid Services
CPG	Clinical Practice Guidelines
CPG-on-FHIR	Representation of CPG recommendations in FHIR
CQL	Clinical Quality Language
CVD	Cardiovascular Disease
DSTU	Draft Standard for Trial Use
eCQM	Electronic Clinical Quality Measure
ELM	Expression Logical Model
FFRDC	Federally Funded Research and Development Center
FHIR®	Fast Healthcare Interoperability Resources
HL7®	Health Level Seven
HTTPS	Hypertext Transfer Protocol Secure
IG	Implementation Guide
IT	Information Technology
LDAP	Lightweight Directory Access Protocol
LDAPS	Lightweight Directory Access Protocol over Secure Sockets Layer

Term	Definition
MeSH	Medical Subject Heading
PCCDS-LN	Patient-Centered Clinical Decision Support Learning Network
PCOR	Patient-Centered Outcomes Research
R4	Release 4
SMART	Substitutable Medical Applications, Reusable Technologies (a FHIR application)
STU	Standard for Trial Use
TLS	Transport Layer Security
UMLS	Unified Medical Language System
VSAC	Value Set Authority Center
WG	CDS Connect Work Group