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Integrating Computer Science across Wyoming's K-12 Curriculum from Inception to Implementation: Analysis Using Systems Theory

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RESEARCH

Abstract

In 2001, the Wyoming Supreme Court ruled in State v. Campbell County that every Wyoming K-12 student has constitutional protection for a fair, complete, and equal education appropriate for the times. This protection results in the universal availability of a "basket of goods," or a set of educational deliverables guaranteed to each student independent of the resources of individual school districts. In 2019, an executive action by Governor Matt Mead added to the deliverables "the use and understanding of computer science." His executive action initiated a system in which universal computer science became available to every Wyoming K-12 student by the 2022–2023 school year. The purpose of this paper is to use archival research methods through the lens of systems theory to explore the process of conceiving and implementing universal K-12 computer science education in Wyoming by considering the research question: How does systems theory provide a model for understanding Wyoming's universal K-12 computer science education delivery? Systems theory has been used to study organizational components and to analyze engineering systems since the 1950s, and a review of the literature indicates that many social systems can be understood through systems theory. However, using systems theory to study educational systems has not been studied in a comprehensive manner, resulting in a literature gap. This study analyzes how Wyoming's universal K-12 computer science delivery acts as a system. This paper provides recommendations from existing conditions to full availability, based on autopoiesis (the ability of a system to maintain itself) and *summum bonum*, or the ultimate good.

Keywords: K-12 Computer Science, Social Systems, Systems Theory

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1 Integrating K-12 Computer Science in Wyoming

Wyoming K-12 students enjoy constitutional protection for a "fair, complete, and equal education, appropriate for the times" ([1] , p.1). The Wyoming Supreme Court declared that education must be delivered consistently throughout all Wyoming school districts, an entitlement that extends to every Wyoming K-12 student. The educational offerings, often referred to as deliverables or a "basket of goods" [1] (p.11), are the right of every Wyoming child. While not unique, Wyoming is unusual in this approach to education, as most school districts rely on local funding models based on property tax. This more common model creates inequity among school districts based on local wealth. Wyoming statutorily protects all students against this kind of inequality [1].

The Wyoming Department of Education (WDE) guides the content and changes to the basket of goods. Beginning in the 2022–2023 school year, universal K-12 computer science education was

added to the deliverables. The initiation of the addition of universal K-12 computer science education began in 2015 with an executive action by then-Governor Matt Mead. The final executive and legislative work are complete, and implementation is underway to make universal K-12 computer science education a reality in Wyoming [2].

While many Wyoming school districts have delivered computer science education, this was not true in all schools and was dependent on district resources. One limiting factor is the presence within the individual districts of qualified teachers. For universal K-12 computer science education to become a reality, every district and most individual schools need access to teachers who have earned a K-12 endorsement in computer science (CS). The process for certifying teachers in CS has begun.

Wyoming's higher education system comprises seven community colleges and the University of Wyoming. Northwest College (NWC) in Powell is one of these community colleges. In the summer of 2020, NWC launched a K-12 CS Endorsement Skills Certificate to qualify in-service teachers in CS to meet Wyoming's evolving vision for education. Thirteen K-12 teachers completed this program in the spring of 2021 and are now certified to teach CS in Wyoming's K-12 schools. The program continues, with additional graduates each year.

This vision for universal K-12 CS education is informed by the Computer Science Teachers' Association K-12 standards [3] and explicated in the Wyoming Computer Science Content Standards:

> Every student in every school has the opportunity to learn computer science. We believe that computing is fundamental to understanding and participating in an increasingly technological society, and it is essential for every Wyoming student to learn as part of a modern education. We see computer science as a subject that provides students with a critical lens for interpreting the world around them and challenges them to explore how computing and technology can expand Wyoming's impact on the world.
>
> *[2]*

The ideals of fair and equal education in general and the universal availability of CS education and its implementation at NWC specifically form the basis of this objective: to help explain Wyoming's process of preparing teachers to provide computer science and computational thinking in their classrooms through the lens of systems theory. This process involves developing a chronology of Wyoming's educational initiative in CS from inception to implementation and recognizing the work of the teachers in the first cohort of NWC's computer science endorsement program. To that end, the following research question is considered: How does systems theory provide a model for understanding Wyoming's universal K-12 CS education delivery?

2 Literature Review

2.1 Archival Research

This study relies on archival research involving primary sources held in repositories. Archival sources include physical records, electronic records, and other materials [4]. Each archival research work is unique because each archive has different resources, access, and constraints. Although generalizing archival work is not uniformly studied, this research paper is based on the construction of a chronology, similar to the methodology used by historians [5].

This study depends heavily on official documents from primary sources: policy, legislation, recorded minutes of meetings, and in-person interviews. Secondary sources, such as newspapers or other media reports, are not used. The use of sequential, official documents from trustworthy sources lends itself to a systematic and incremental study with minimal ideological bias [6].

2.2 Classical Systems Theory

System theory asserts that the design of a system predicts the outcome, and if the outcome is undesirable, the individual system components can be modified to alter the output. When systems theory is applied to engineering systems, meaning is created from the interactions of many different components [7] .

Adams et al. [8] outlined the history of systems thought by summarizing definitions provided by the four foundational researchers. Von Bertalanffy [9] focused on the formal correspondence of general principles, regardless of the relationships between system components, while [10] viewed general systems theory as a framework or structure on which to "hang flesh and blood" to develop an orderly and coherent body of knowledge relevant to different disciplines. Building on these foundational researchers, [11] conceptualized systems theory as a way to view phenomena as interrelated rather than isolated, which provides a way to study the complexity of a system, and [12] focused on the relationships between systems and subsystems. He studied the ideas of optimization and suboptimization and the sometimes "fruitless" efforts expended in the pursuit of summum bonum, or the "ultimate good." From classical systems analysis, the entirety of the universe is divided into two elements: a system and its surroundings [13].

Regardless of the field of application, systems can be designed for *summum bonum* but often fall short of this goal. Keating et al. [14] postulated that suboptimization may be a more appropriate goal in terms of the expenditure of resources.

In summary, systems theory is used to analyze complex organizations, considering parts of the system as they relate to each other as the system aims to achieve desired outcomes. The outcome of the system is viewed as the end-product of the components; if desired outcomes are not achieved, the components of the system are examined and changed until the desired outcomes are achieved. From a practical standpoint, a goal of suboptimization may be more efficient a goal than optimization due to the expenditure of less fruitless effort.

2.3 Systems Theory Applied to Social Sciences

The problems facing the modern world are complex and systemic by nature and cannot be understood in isolation [5]. Interconnectedness and interdependence must be considered in the analysis of modern social systems, and studying human organizations using systems theory is timely and important. [5] emphasized the importance of the role of dialog in the decision-making process of social systems. Additionally, she developed the possibility of using systems theory in a less technical, more humanistic way when applied to human systems instead of engineering systems, broadening the applicability of systems theory to a wide array of social problems.

There are differing views of how systems theory applies to social systems [8], but central to the research is the concept of communication and interconnectedness as key components of any social system [15–17] with self-sustainability as a goal.

Modern systems theory applied to social systems is based upon a social constructivist understanding of social reality, where meaning is constructed through communication [15]. [17] postulated that changes in social systems occur through communication, and [16] saw communication media as the "universal key," or a "super methodology" to explain systems process. The literature is clear on the importance of communication within a social system; some authors go so far as to say that the system is created by communication alone [17].

Another key element of systems theory is that social systems are viewed as holistic, meaning that the individual components of the system are interrelated and can only be analyzed with respect to other components [18]. A holistic system can become capable of decision-making and self-management. This concept is called autopoiesis, which means self-production [19]. [20] tells us that any system requiring "human vigilance" will degrade over time; when autopoiesis is achieved, constant intervention is no longer necessary for the system to continue functioning, as the system becomes self-sustaining. This is a working definition of autopoiesis.

The extent to which autopoiesis can be applied to social systems is debated. [21] argued that autopoiesis is a fundamental concept of constructivist epistemology and applies to social systems if the definition is focused to mean self-sustaining. Similarly, a systems-thinking framework reflects upon the end-user's experiences [22–24].

[8] proposed a definition of systems theory as applied to social systems. He articulated this definition by enumerating the following set of axioms to form a system construct, shown below in Table 1 .

Table 1. Axioms for Systems Theory Construct

Axiom	Description
Centrality	Communication and control create feedback as the dominant system building block
Contextual	System meaning is informed by the circumstances and factors surrounding the system
Goal	Systems achieve specific goals through purposeful behavior using pathways and means
Operational	Removing a system from its environment changes its behavior; systems must be studied where they operate (in situ).
Viability	Key parameters in a system must be controlled to ensure continued existence (autopoiesis)
Design	System design is a purposeful imbalance of resources and relationships
Information	Human systems create, possess, transfer, and modify information

From [8]

In summary, systems theory can be applied to social systems when the definitions of component and autopoiesis are focused to mean communication and self-sustaining. Under these conditions, a social system can be analyzed using Adams' et al. [8] axioms to characterize the system.

Literature Gap

This study focuses on the content and application of systems theory to an educational organization. Systems theory has been widely applied to study engineering systems, and more recently has been investigated to study social systems. However, a gap in the literature exists when considering educational systems using systems theory. Banathy and Jenlink [25] stated the following:

> With very few exceptions, systems philosophy, systems theory, and systems methodology as subjects of study and applications are only recently emerging as topics of consideration in educational professional development programs, and then only in limited scope. Generally, capability in systems inquiry is limited to specialized interest groups in the educational research community. It is our firm belief that unless our educational communities and our educational professional organizations embrace systems inquiry, and unless our research agencies learn to pursue systems inquiry, the notions of "systemic reform" and "systemic approaches to educational renewal" will remain a hollow and meaningless rhetoric.
>
> *[25] (p. 47)*

Based on this literature gap, it is appropriate and important to study educational systems, such as the delivery of universal K-12 education in Wyoming, using systems theory.

3 Context of the Study

3.1 Wyoming's K-12 Computer Science Initiative

In 2019, then-Governor Matt Mead issued an executive action to include "the use and understanding of computer science" to the educational deliverables guaranteed to each Wyoming K-12 student. This initiative was part of the Wyoming Innovation Network/Wyoming Innovation Partnership (WIN/WIP) and was the first step in the delivery of universal CS education in Wyoming K-12 schools [26, 27] .

Following the executive action, the governor's office created a task force to determine how to implement the action, and a legislative committee was empaneled to study CS in Wyoming's K-12 schools. The committee sponsored 18LSO0221 "Education – Computer Science and Computational Thinking" at its November 14, 2018 meeting for sponsorship during the 2019 legislative Session. The bill was passed as SF0029, "Education – Computer Science and Computational Thinking" [28], and implemented through the Wyoming Legislature. Table 2 describes the measures enacted by SF0029.

Table 2. Measures Enacted by SF0029

Action	Item	Standards
Added	Computer Science	Common Core of Knowledge
Added	Computational Thinking	Common Core of Skills
Authorized	Use of a CS course	High School graduation requirements and Hathaway Success Curriculum

In response to SF0029, the WDE developed the Wyoming CS Content Standards [29] . These standards are based on the seven practices enumerated in Table 3 .

Table 3. WDE CS Content Standards

Practice	Description
1	Fostering an inclusive computing culture
2	Collaborating around computing
3	Recognizing and defining computational problems
4	Developing and using abstractions
5	Creating computational artifacts
6	Testing and refining computational artifacts
7	Communicating about computing

Following SF0029, the Professional Teaching Standards Board (PTSB) began the process of certifying K-12 teachers to teach CS in Wyoming schools. One method of certification is for practicing teachers to earn a K-12 CS Endorsement Skills Certificate through a Wyoming institution of higher education, then use this endorsement to apply to the PTSB for certification. Six of Wyoming's community colleges and the University of Wyoming have created K-12 Computer Science Endorsement Skills Certificates based upon these standards and PTSB requirements. Each program shares eight credits in two common classes (Introduction to Computer Science and Computer Science I), and completion of each program requires 15 to 20 semester credits [30, 31] . The remaining 7 to 12 credits are selected from various courses, including social media, robotics, web design, and additional courses in computer science.

All endorsement programs must be approved through the PTSB. Additionally, all programs offered by Wyoming Community Colleges must be approved by the Wyoming Community College Commission (WCCC).

3.2 Current State of NWC's K-12 CS Endorsement Program

In response to SF0029, NWC formed a faculty development team to create the curriculum for the K-12 CS Endorsement Skills Certificate. The coursework was selected and refined based on the WDE CS Content and Performance Standards, in conjunction with PTSB requirements. The skills certificate consists of 15 semester credits, distributed among five courses. Two of these courses (Introduction to Computer Science and Computer Science I) were existing catalog courses that address Practices 3, 4, 5, and 6 of the Wyoming Department of Education Computer Science Standards. Robotics was modified from an existing catalog course to address Practices 2 and 3 [32]. Two new courses were created: Application Development and Social Media for K-12 Teachers [33]. Application Development addresses Practices 5 and 6, whereas Social Media for K-12 Teachers addresses Practices 1, 2, and 7 [28, 29].

The first step in the internal approval process was for the faculty development team to present the K-12 Computer Science Skills Certificate to NWC's Curriculum Committee. New courses and the modified course required approval as NWC catalog courses, and the program required preliminary approval as a skills certificate. The courses and certificate program were approved at the regular meeting on December 10, 2019 [34] .

The next step toward approval was for NWC administration to bring the skills certificate to the Wyoming PTSB for consideration as an endorsement program for certified teachers to teach CS within their grade bands. The program was presented and approved for endorsement in January 2020 [31].

The final step was to seek approval from the WCCC for the K-12 CS endorsement program to be approved as a skills certificate. This approval was granted at the regular meeting of the WCCC held on April 16, 2020, and now, the path was cleared to begin offering the skills certificate to in-service teachers who wanted to earn K-12 CS endorsements [35].

The teachers in NWC's first cohort completed Introduction to Computer Science in the 2020 summer semester, followed by Computer Science I and Social Media for K-12 teachers in the fall of 2020. In the spring 2021 semester, the teachers completed Application Development, and they finished their skills certificate with Robotics in the 2021 summer semester. In total, 13 teachers earned their skills certificates and endorsements in 2021.

Based on the results of the initial offering, the general format was found to be effective, and NWC will continue to serve its constituency and meet its mission by refining the K-12 CS endorsement program to remain relevant over time [28].

In the summer semester of 2021, a second cohort of six teachers began coursework for the K-12 CS Skills Certificate. Based on feedback from the first cohort, minor modifications to the schedule were introduced, and these six teachers are on schedule to earn their CS Skills Certificates in the Summer of 2022. Future classes follow the same general outline with modifications to the schedule and content determined based on student feedback. Further curriculum refinement, including the introduction of different programming languages and environments, will be determined in cooperation with the faculty development team and student feedback.

4 Methods and Results

The methodology to address the research question "How does systems theory provide a model for understanding Wyoming's universal K-12 CS education delivery?" is qualitative, using archival research methods. The theoretical framework of systems theory is used to interpret the archival research, and the methods focus on understanding the wholeness of the delivery of universal CS education in Wyoming as a social system [36]. Analysis requires examining individual steps, but systems theory integrates these steps into an interconnected whole.

4.1 Credibility and Trustworthiness (Reliability and Validity)

The trustworthiness of archival research depends on the veracity of the documents studied. Bias is minimized because the documents are prepared by sources other than the researcher. As [37] states, "We can trust a text if it is the work of an individual or group of individuals whom we can trust". This study relies heavily on official documents from primary sources: policy, legislation, official press releases, and recorded minutes of meetings. The use of sequential, official documents from trustworthy sources lends itself to a systematic and incremental study with minimal ideological bias [6].

Because of the vast array of available documents, selecting viable documents from well-grounded sources is key to establishing credibility and trustworthiness. Studying these documents in a systematic process creates a body of evidence that can be analyzed using systems theory.

4.2 Procedures

The archival research was conducted primarily through the electronic retrieval of official documents, searching for the "next steps" as determined by the previous step, and finding documents created based on prior documents. Every official document used was a compilation or continuation of many other documents and conversations codified into a single instance of an official document. This procedure allowed for a systematic study, resulting in a logical chronology of events leading from one to the other based on official accounts from credible sources.

5 Analysis

The analysis below explains the data flow and interconnectedness of the system using centrality and contextual axioms [8]. The perspective follows Grothe-Hammer's [17] view of communication as the sole component of the system.

5.1 Analysis Using the Centrality Axiom

The centrality axiom [8] facilitates a discussion of communications between nodes to identify where and how decisions are made and how they influence the rest of the system. The starting point of the analyzed system is the WIN/WIP executive action by Governor Mead to introduce universal K-12 computer science to Wyoming K-12 schools. The endpoint is Wyoming teachers who earned endorsements to teach K-12 CS through NWC. This start and end represent the current boundaries of the system, which were created to narrow the focus of the analysis. Similar systems could be constructed for teachers completing other endorsement programs. Table 4 describes the pathway for certifying K-12 CS teachers through NWC's approved skills certificate, displaying the data flow between each system node. The chronology of the system moves forward based on data flow rather than on a narrative, as it does in traditional archival research. Data flow occurs between nodes that define the points of contribution to the system [38] .

Because full implementation is now in the earliest stage, the availability of universal K-12 CS education in Wyoming is viewed as a data flow out of the system. After full implementation, this aspect could be reanalyzed as the endpoint of the system.

5.2 Analysis Using the Contextual Axiom

The contextual axiom examines the circumstances and factors surrounding the system [8]. The system is acted upon by external inputs and delivers external outputs. Both inputs and output occur through the data flow.

Figure 1 presents a context-level system diagram. The system is teachers endorsed in K-12 computer science through NWC, which is identical to the endpoint of the system analyzed using

Table 4. Applying the Centrality Axiom to the pathway for certifying K-12 CS teachers through NWC's skills certificate program

Node	Description	Communication	Decision
1	Executive Action	WIN Initiative/SEA0029	Development of legislation
2	Statute SEA0029	Vote by Wyoming legislature	Majority vote passes statute into law (SF0029)
3	WDE	Content and Performance Standards	See below
> 3.1	WDE	Content Standards: CS Standards Review committee empaneled. Standards developed collaboratively to include public input	Approved 1/4/2020
> 3.2	WDE	Performance Standards: based on Content Standards, twelve teachers from the original CS Standards Review committee determined performance standards and the required deliverables from the content standards	Approved 4/7/2021
4	NWC Faculty Development Team	Development of coursework and delivery methods leading to K-12 CS endorsement for certified teachers	Creation of a program of study for K-12 CS Endorsement skills certificate
5	NWC Curriculum Committee	Faculty development team presents curriculum to NWC's curriculum committee at the regular meeting	A majority vote approves and enacts K-12 CS endorsement Skills Certificate program of study
6	WCCC	WCCC meeting to review K-12 CS endorsement skills certificate program of study	Approval by majority vote to implement K-12 CS endorsement Skills Certificate
7	PTSB	PTSB meeting to review program of study	Approval by majority vote to certify K-12 CS endorsement Skills Certificate to fulfill requirement to certify teachers
8	Delivery of curriculum	NWC faculty team delivers the curriculum to first cohort of teachers	13 teachers earn K-12 CS endorsement Skills Certificate from NWC and certification from PTSB
9	Endorsed teachers	Future: teachers to develop and deliver universal K-12 computer science education to Wyoming K-12 students.	Future: universal K-12 computer science education delivered to Wyoming students by certified teachers

the centrality axiom (Node 9). Nodes 1 to 8 are external inputs and outputs to the system, and communications are data flows.

Figure 1

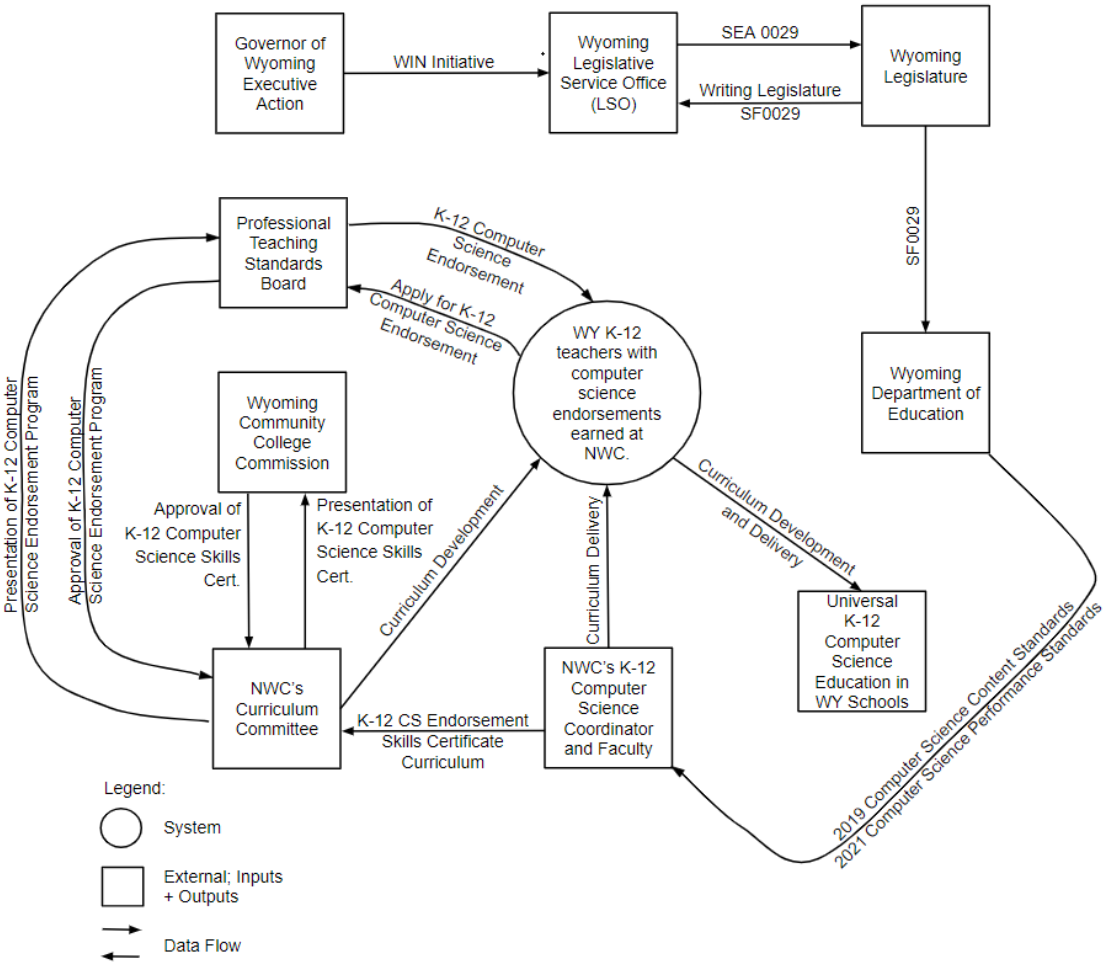

Figure 1. Context-Level System Diagram

5.2.1 Results/Findings

This study outlines the process of delivering universal K-12 CS education to Wyoming K-12 students and analyzes the process using systems theory. Using the centrality axiom [8], the analysis results in a flow chart that accurately models the behavior of this delivery as an organization described as a social system. The process can also be viewed at the context level using the context axiom [8]. The analysis results in a context-level system diagram that accurately models the behavior as an organization described as a social system. Together, these indicate the validity of viewing universal K-12 computer science delivery in Wyoming using systems theory as applied to a social system.

The goal (output or product) of the system is to ensure current K-12 teachers are certified to teach CS in Wyoming's K-12 schools. The delivery of this education is viewed as a data flow from the system because universal K-12 computer science began in the 2022–2023 school year.

5.2.2 Limitations and Future Research

The time required to deliver universal K-12 computer science education in Wyoming is a potential topic for future study and may represent a suboptimization of the system. Zac Opps, a content expert in K-12 robotics, raised the question regarding what nodes and data flows could be optimized to increase delivery speed. As a former K-12 teacher now working for Digital Promise, a nonprofit organization with a goal of closing the digital learning gap by accelerating innovation in education and improving opportunities to learn [39] , Opps suggested that it is inefficient that a low-population state like Wyoming could take nearly a decade to implement universal CS education. While many districts have already done so, creating a reliable system in which every Wyoming K-12 student has guaranteed access is far from complete and does not meet the goal of the state of Wyoming to deliver universal CS education. Unforeseen delays in timing and other delivery barriers can be studied at the district and school levels, then considered as part of the system.

A current limitation is that implementation is in the earliest stages. Future steps should extend the systems analysis to include the full implementation of universal K-12 CS in Wyoming schools as the output of the system.

Universal K-12 computer science was implemented during the 2022–2023 school year, and future research to analyze the effectiveness of universal K-12 CS education can be determined using systems theory can be undertaken in the future.

6 Conclusions

"We tell ourselves stories in order to live." So begins The White Album, an essay by Joan Didion ([40] , p.1).

When Didion wrote that statement, she was referring to the basic human need to construct order from chaos. How is the disorder of life made orderly? She went on to say, "We interpret what we see, select the most workable of the multiple choices" ([31, 40] , p.1). On one level, Didion's essay refers to literature. On another level, she discusses writing a chronology from newspaper articles and firsthand accounts: in essence, The White Album is a work of archival research. Separate documents from different sources are gathered and arranged in an order that provides structure and connections between seemingly unconnected events, creating a narrative with chronology, form, and ultimately, meaning.

This study tells the narrative of Wyoming's universal K-12 CS delivery initiative. The research question "How does systems theory provide a model for understanding Wyoming's delivery of universal K-12 computer science education?" is answered by considering Wyoming's K-12 CS initiative chronologically based on archival research then viewed through the lens of systems theory to give the story form and meaning.

Whether or not Wyoming's CS initiative is a system that attains autopoiesis is yet to be determined: Implementation began in the 2022-2023 school year, and more data should be gathered and analyzed to determine whether the system becomes self-sustaining. Systems theory tells us that if the system begins to degrade over time, the components – the communication feedback loops – can be examined to determine where problems lie. Corrections can be made at the component level to achieve the desired output. These corrections will enable the system to become self-sustaining.

The desired output (*summum bonum*, or the ultimate good) may be optimization, but suboptimization may be determined to be the goal. As an example, the long time span required to implement the delivery of K-12 CS education may be appropriate if speeding things up would be too costly, or if a longer time frame is required to make the changes needed to keep K-12 CS education relevant under changing conditions.

In conclusion, the delivery of universal K-12 CS education in Wyoming can be viewed as a system.

Using the centrality axiom with communication viewed as the sole component of the system, a logical and systematic view of the system is developed. Whether the system attains autopoiesis will become known when universal CS education is delivered in all Wyoming school districts and a determination of whether the system degrades or self-regulates can be made. The long time period required for implementation may indicate that the system is not optimized, but a sufficient degree of suboptimization may be determined to be the most appropriate goal. If communication between all inputs and outputs exists in a self-regulating manner, the feedback loop at each juncture can be analyzed and improvements made at the component level could result in a more efficient system.

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