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STEM EMBEDDED IN THE DUJIANGYAN IRRIGATION SYSTEM: A DESCRIPTIVE - INTERPRETIVE ANALYSIS TO DESIGN STEM COURSE

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Abstract. *STEM (science, technology, engineering, and mathematics) education is recognized as the world's top education program. However, few STEM programs have been designed based on cultural-historical events. To explore this issue, the present study drew on the cultural-historical activity theory and the content analysis method by adopting the descriptive-interpretative approach to explore the STEM content of the Dujiangyan Irrigation System (DIS) in present-day Sichuan, China. As early as 2,275 years ago during the Warring States period, Li Bing, the governor of Shu Shire in the Qin state, implicitly implemented the STEM concept when building the irrigation system. The results of this study indicate that the DIS incorporates Science (e.g., the hydraulic principle), Technology (e.g., making a large cobblestone Bamboo-Cage for building Fish Mouth), Engineering (e.g., water-level measurement) and Mathematics (e.g., Calculation of sand discharge). Adopting an educational pedagogy proposed by UNESCO which emphasized learning concepts from daily life, the present study draws on a cultural-historical event to inform STEM learning. The method and results of this study can be applied in the design of STEM programs based on other cultural-historical events from around the world.*

Keywords: *cultural-historical activity theory, Dujiangyan, hydraulic engineering, interdisciplinary knowledge, STEM*

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Introduction

Science, Technology, Engineering and Mathematics (STEM) education is recognized as the world's top educational project (Sergis et al., 2019). Training a sufficient number of graduates in STEM-related occupations has thus become an important policy concern in many developed countries (Park et al., 2018). In recent years, STEM has been widely advocated and implemented in education because it is considered to have a great impact on students' interdisciplinary learning, which can be seen as an important driving force for the progress of a country (Kuo et al., 2019). The abbreviation of STEM was created by the National Science Foundation (NSF) in the United States in the 1990s (English, 2016). Previous research has revealed that current STEM courses mainly consist of robotics courses (Castro et al., 2018), mathematics courses (Kim & Sax, 2018), or coding courses (Tran, 2018). Although the number of STEM courses in the United States is rapidly increasing, few integrated STEM courses have been developed (Kelley & Knowles, 2016). It is therefore necessary to develop more integrated courses.

UNESCO (2003) proposed the concept of "learning science knowledge from culture-history" as "being close to STEM." As learning content designed to incorporate historical events is being gradually and widely adopted by teachers (Lewin et al., 2018), analyzing the learning content based on Cultural-Historical Activity Theory (CHAT) would be helpful for meaningful STEM learning and practice (Lim, 2019). For example, Irwin (2000) suggested a variety of benefits when teaching students to understand the nature of science by teaching specific historical cases. However, historical projects tend not to be popular in curriculum teaching, especially the analysis of their STEM content (Shafto et al., 2014). Considering that CHAT not only allows researchers to explore the meaning of cultural-historical activities, but also to develop a research framework to understand the "undiscovered knowledge" over a long period of history (Lim, 2019, p. 332), this study analyzed the connotations of the Dujiangyan Irrigation System (DIS) (i.e., an ancient irrigation system in present-day Sichuan province, China) as STEM learning content.

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There are a variety of curriculum design models that can be used to develop appropriate curriculum content (Davis, 2013). Among the many models, Bobbitt (1918) suggested that various human activity models can be analyzed via spiral development. For example, Bruner's spiral curriculum (1960) is an approach to curriculum design that involves re-visiting the same learning topics over the period of a course. This approach has the benefits of updating information over time and using prior content to inform and adjust knowledge (Harden & Stamper, 1999). By adapting the spiral model of course development, a STEM course was developed based on CHAT; that is, this study analyzed the STEM content of the DIS using a spiral model to construct the reference content for the implementation of STEM teaching.

Theoretical Background

The practice of STEM involves the practice of the four identifiable disciplines of Science, Technology, Engineering, and Mathematics (Hobbs et al., 2018). However, STEM does not teach mathematics and scientific knowledge independently; rather, it encourages students to integrate multiple subjects and practice topic design with a high degree of thinking ability to try to solve real-life problems and cultivate the innovations needed for competition (D'Ambrosio, 2019). As STEM education gains more attention in schools, many possibilities can be proposed for young students to build a foundation in STEM learning (Watson et al., 2020). There are many definitions of STEM without a standard explanation. For example, Zandvliet (2018) pointed out that students of the STEM education model are required to understand environmental issues within prescribed or predetermined limits. Thus, the present research focused on analyzing DIS as an environmental issue for STEM course design.

Science

"Science" mainly refers to natural science and other similar research fields (Hansson, 2015). Since it is about seeking truth and new knowledge, the pursuit of science is called basic research (Bhushan, 2015). In addition, the Oxford English Dictionary (2019a) defines science as the intellectual and practical activity encompassing the fields of physics, biology, chemistry, earth science, biochemistry (hybrid), biotechnology and biomedicine. Science is "mastering the properties of materials, the interactions and changes between materials" (McAuliffe, 2016). Based on this definition, this study explored the scientific concepts of Dujiangyan.

Technology

Technology is based on applying natural science to achieve human goals (Roco & Bainbridge, 2003). The Oxford English Dictionary (2019b) defines Technology as the application of scientific knowledge for practical purposes, especially in industry where it is applied for the development of machinery and equipment. It has been pointed out that Technology includes, but is not limited to, the fields of construction, production, agriculture, communications, transportation, power and energy, industry and information technology (McAuliffe, 2016). Therefore, this study defined Technology as the "application of appliances to generate or change objects' functions or powers, and processing methods or approaches with tools and/or powers" other than human hands to explore the application of Technology in Dujiangyan.

Engineering

The Oxford English Dictionary (2019c) defines engineering as the branch of science and technology concerned with the design, building and use of machines and structures. The National Research Council (2012) defines "Engineering" as any participating system design practice to achieve the "best solution" to specific human problems. Engineering covers domains including electrical, computer, aerospace, machinery, industrial, mechatronics, medical, materials, marine, environment, fluids, and so on (McAuliffe, 2016). In various Engineering "operations and functions" under limited conditions, the best use of resources, maximized function, minimized technical contradiction, exquisite function, stability, persistence, and the smooth operation of mutual braking between objects are emphasized. Based on this, this study analyzed the meaning of Engineering in terms of the Dujiangyan system.

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Mathematics

The Oxford English Dictionary (2019d) indicates that mathematics includes abstract pure mathematical concepts, abstract quantitative science (such as quantity and space), and applied mathematics which is applied to other disciplines such as physics and engineering. The definitions that have evolved from them (such as angles, horizontal lines, vertical lines, geometric figures) include principle axioms or assumptions (Khan, 2015). The field of mathematics covers, but is not limited to, algebra, geometry, trigonometry, calculus and theory (McAuliffe, 2016). This study explored the mathematical application in Dujiangyan according to this concept.

Research Purpose and Questions

Engeström (2018) noted that knowledge frozen in histories must be specifically classified in order to be successfully transformed into learnable knowledge. Among the many well-known ancient construction projects, DIS is a rare example in human civilization of a STEM construction. The designers of DIS made good use of local resources to build a weir project in ancient times in the absence of modern technology and material applications.

According to Nonaka and Takeuchi (1995), knowledge is classified into tacit knowledge and explicit knowledge (Park & Gabbard, 2018). However, at present, little knowledge of historical engineering in the teaching design model is interpreted as explicit STEM knowledge. Although these STEM terms were not clearly defined or proposed in ancient times, the weir-building project at that time involved a kind of tacit STEM knowledge. Only when this tacit STEM knowledge is turned into explicit knowledge can it be integrated into STEM curriculum teaching. Therefore, the purpose of this research was to turn DIS into STEM content suitable for 10th-grade students. At the same time, this research proposes the following two research questions.

1. What STEM elements are used in the upstream of Dujiangyan Irrigation System?
2. Is it feasible to conduct STEM teaching topics from a historical and cultural perspective?

Research Methodology

Analytical Method

To analyze the integration of subject knowledge, this study used the "description-interpretive" method (DIM) to analyze the learning content of DIS. The DIM emphasizes the subjectivity of reflection. It focuses on the understanding of reality and claims to acquire knowledge (Walther et al., 2013). DIM includes "describing" in which situations the phenomenon appears and the scope it covers, and "interpreting" what the significance of the phenomenon is (Elliott & Timulak, 2005). For more confidence in applying DIM, this study adopted a spiral approach to ensure the quality of the course design. The spiral approach to curriculum design has three key principles that sum up the approach nicely. They are (Lohani et al., 2005): 1) Cyclical: The designers should return to the same topic several times. 2) Increasing Depth: Each time designers return to the topic for a deeper exploration. 3) Prior Knowledge: Previous content should be utilized when a topic is returned to. Considering this, three domain experts were invited to describe the three phases of reinterpretation to analyze the STEM learning content of DIS. These three experts each had at least 5 years of STEM professional teaching experience and participated in the study to establish face validity by reviewing whether the use of DIS was appropriate for the illustration of STEM content.

Descriptive Analysis of Dujiangyan

Floods cause great destruction, and such disasters often occur in Asia (including China) (Luo et al., 2015). During the Warring States Period (475-221 BC), the Minjiang River, the longest tributary of the Yangtze River in the mountainous region of Southeast China, experienced rapid turbulence. When it straddled the Chengdu Plain, it often flooded agricultural areas (Guo, 2019) because it suddenly dropped from 3,000 m to 600-1,000 m above sea level, exposing the plain to the serious danger of flooding. In 256 BC, during the Warring States period, Bin Li of Shu County in the Qin Kingdom led a team to build the DIS (Cao et al., 2010) on the Minjiang River west of Dujiangyan City, present-day Sichuan Province. DIS was constructed as a dam-free project (Luo et al., 2010).

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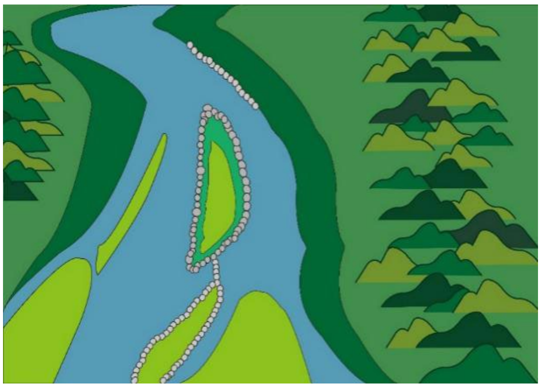
Moreover, Takeuchi (2004) pointed out that DIS has provided Chengdu with a safe water intake area, regardless of whether floods or droughts occur. DIS is currently managing the water use of 320,000 hectares of land, with a total irrigated area of 673,333 hectares (Li & Xu, 2006). Besides its ecological value, DIS is considered to have a certain academic value in terms of the design and construction of modern water conservancy projects (Zhang et al., 2012). Due to DIS having rich historical and scientific value (Ji, 2018), it was included in the World Heritage List in 2000. It is a historical and cultural heritage site with a design concept that is more than 2,000 years old (World Heritage Center, UNESCO, 2009) and has maintained good operation for 2,275 years. The design of DIS included three major parts: Fish mouth (watershed), Flying Sand Sluice (sand drainage and spillway), and Baopingkou (water intake) (Li & Xu, 2006).

Dujiangyan Features: Structure

Fish Mouth is a diversion dam that divides the water of the Minjiang River into two rivers, namely the outer river and the inner river. Flying Sand Sluice is a spillway used to remove the sand and excess water from the inner river to the outer river during floods. Baopingkou is the entrance to the irrigation system which can automatically control the intake of water, ensuring a stable flow (Li & Xu, 2006) (see Figure 1). Therefore, in DIS, problems such as sand drainage, flood control, and water supply are solved simultaneously (Cao et al., 2010). In addition, the DIS dam was not a permanent installation. China had not invented cement at that time, so Bamboo-Cages filled with cobblestones were used instead. This method is easy to construct and dismantle, and it can be rebuilt in the same year if destroyed by flooding (Peng, 2008). Thus, DIS conforms to modern principles such as hydraulics, river dynamics, hydrology, geomorphology, and systems engineering (Cao et al., 2010; Wu, 1986), with cross-disciplinary knowledge of natural sciences, technology, and engineering (Peng, 2006).

Figure 1
Schematic Diagram of Dujiangyan



The location, structure, size, height, direction, angle and other layouts of DIS are combined with the river regime of the Minjiang River strait, the mountain straits on both banks, and the incoming water and sand conditions of the upper reaches of the river in different seasons to form a perfect whole to achieve water diversion, flood discharge, sediment drainage and other effects (Li, 2008).

Fish Mouth

Fish Mouth is a diversion dam (Li & Xu, 2006) located at the heart of the upper reaches of the Minjiang River. It is a wedge-shaped artificial island made of large cobblestones in long Bamboo-Cages, stacked crosswise in order to reverse the current. The function of Fish Mouth is to divide the water flow of the Minjiang River into two streams, where the water flow to the right is the inner river with the water flowing to Baopingkou, while the left is the outer river with the water continuing to flow to the south (Chen, 2011; Murphy, 2002), achieving the efficacy of flood drainage by the outer river and water diversion irrigation by the inner river (see Figure 2).

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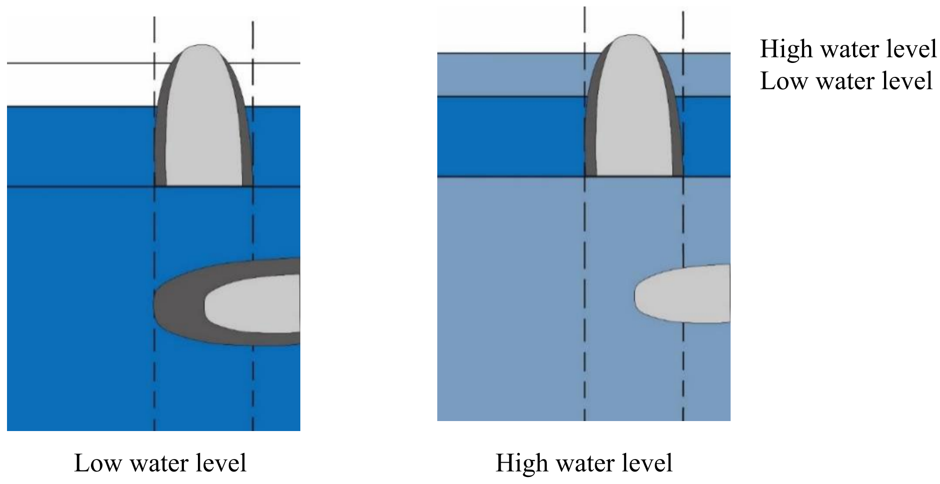
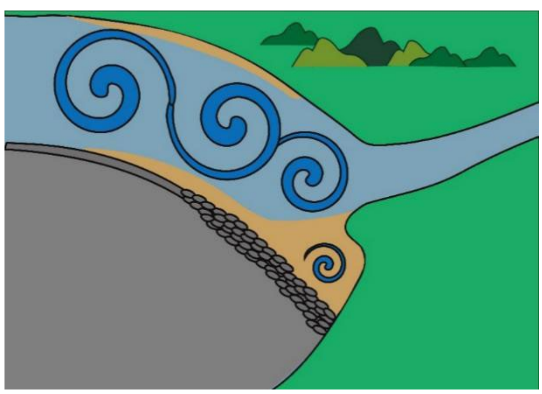
Figure 2
Fish Mouth



Flying Sand Sluice

The Minjiang River is a turbulent river with a great deal of sediment and gravel of different sizes. Therefore, in the middle part of Dujiangyan, a spillway with a width of more than 200 meters and a height of 2 meters was built and named Flying Sand Sluice (Duan, 2012). During the flood period, when the water level of the inner river rises above a certain level, the water level of the inner river rises over Flying Sand Sluice, and excessive water and gravel will overflow to the outer river through Flying Sand Sluice (Liu & Wang, 2016). This meets the use of the irrigation water on one hand and transports sediments on the other hand (Luo et al., 2015). In addition, there is a curve in the river downstream of Flying Sand Sluice. The Hutouyan-Fengqiwo river section is located on the convex bank as a sediment accumulation area, and the dredging here further reduces the sediment entering the irrigation area via Baopingkou (Fang & Li, 2015) (see Figure 3). This has successfully solved the sedimentation problem, greatly reducing the potential damage caused by gravel during the flood season (Li & Xu, 2006).

Figure 3
Flying Sand Sluice -1



The role of Flying Sand Sluice is mainly for excess water to overflow from Flying Sand Sluice when the amount of water in the inner river reaches the upper limit of the flow of Baopingkou. However, in the event of a severe flood, the artificial weir on the left of Flying Sand Sluice will burst (there is a mountain to the right), allowing a large amount of river water to flow into the mainstream of the Minjiang River for flood diversion (see Figure 4).

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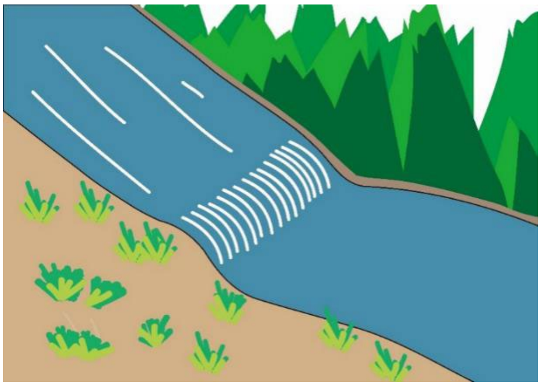
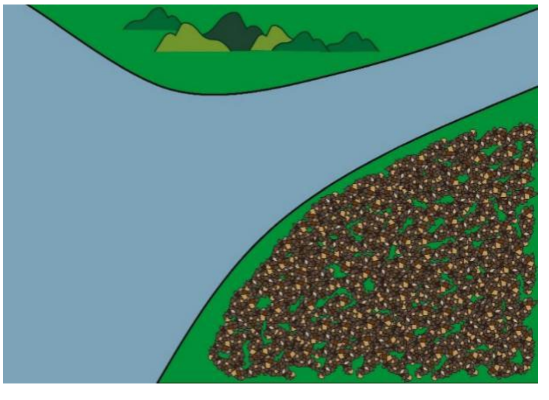
Figure 4
Flying Sand Sluice -2



Baopingkou

Baopingkou has the function of a check sluice and can automatically control the inflow of the inner river (Wang & Wu, 2017) (see Figure 5). Because its narrow opening is used as a control feature, it can prevent floods from entering the irrigated area (Jin, 1988). The 1:1 flow control for water flow can achieve the effect of preventing and controlling floods (Liu & Wang, 2016). In addition, the water depth of the Baopingkou can reach the stability level of "dried up water level below [the] feet and full water level up to [the] shoulders" (Li, 2008) of the stone statues placed in the river. The shape of the water inlet in this section is similar to that of a bottle mouth, so it is called "Baopingkou" (which means "precious bottle mouth" in Chinese). After Yulei Mountain was dug, the stripped stone pile was called "Lidui," and the channel after Lidui was extended by the locals.

Figure 5
Baopingkou



Dujiangyan's Water Diversion Measures: 4:6 Water Diversion to Eliminate Flood and Drought

"Diverting the water in the proportion of four to six so that the irrigated area will neither flood nor dry up" is an important diversion measure in DIS, and this diversion is carried out at Fish Mouth. Fish Mouth divides the Minjiang River into the inner and outer rivers, where the inner river is deep and narrow, and the outer river is relatively shallow and wide (Fu et al., 2018), prompting DIS to achieve diversion irrigation and reduce flooding and subsequent disasters (Liu, 2008). When the amount of incoming water from the Minjiang River is less than 500 m^3/s, the diversion of the inner river and the outer river is 6:4; and when the amount of incoming water from the Minjiang River is more than 500 m^3/s, the water flow division ratio between the inner and outer rivers becomes

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4:6 (Li, 2004). This ensures that the flow of the rivers into the irrigation system during the dry season is about 60%, and during the flood period, it is reduced to about 40% (Fu et al., 2018).

The diversion principle is that, as the water level of the Minjiang River fluctuates and Fish Mouth is submerged to various degrees, the angle changes accordingly, which plays a role in regulating the flow of the inner and outer rivers. During the dry season when the flow of the Minjiang River is small, the water flow bends. The mainstream bypasses Fish Mouth and enters the inner river, so that the inner river can receive 60% of the water volume. This provides water for spring ploughing in the irrigation area. At this time, the outer river only receives 40% of the water. Most of Fish Mouth is submerged in the flood season, and the water surface slope of the Minjiang River is larger so that it can flow in a straight manner. The inlet of the outer river is directly opposite the water flow in the upper Minjiang River. However, today the inner river diversion in Dujiangyan is about 75% during the spring irrigation period, and about 37.5% in the flood period (Liu & Wang, 2016).

Dujiangyan's Annual Repair System: Digging Deep in The Riverbed and Building A Low Weir

The weir body constructed by the ancient Bamboo-Cage structure is still not completely stable under the impact of the Minjiang River rapids. Although the inner river channel has a sand drainage mechanism, it still cannot completely avoid sand and stone deposition, so regular annual repairs are required for DIS to continue to work effectively. The principle of annual repair is to "dig deep in the riverbed and build a low weir." In ancient times, digging deep in the riverbed meant that people had to dig to a depth below the stone horses in the riverbed of Fengqiwo. However, the stone horses were replaced by iron plates during the time of the Zhengde emperor of the Ming Dynasty, and then were changed to three lying irons during the reign of Tongzhi in the Qing dynasty (Deng & Zheng, 2013).

Therefore, the "digging deep in the riverbed" as referred to in modern times refers to the silt clearing in Fengqiwo on the opposite bank of Flying Sand Sluice during the period of annual repair. The digging continues until the buried lying irons are exposed. At present, four lying irons are buried in Fengqiwo. These four lying irons are 4 m in length and 20 cm in diameter and are 1.7 m apart from each other. Their height is 2.2m lower than that of Flying Sand Sluice (Li & Li, 2017). If it is dug to the iron pile, it would cause the riverbed in the inner river to be too high, which reduces the amount of water entering the mouth of Baopingkou, and adversely affects the diversion of the irrigation area in the year (Lo, 2016). "Building a low weir" refers to the weir top engineering of Flying Sand Sluice. At present, the weir top in the middle of Flying Sand Sluice is 2.05m above the riverbed (Li & Li, 2017).

Research Results

Scientific Application in Dujiangyan

Physics - Thermal expansion and contraction

Excavating rocks from the mountains was a difficult and time-consuming engineering task at the time of construction because gunpowder had not yet been invented. Therefore, the Dujiangyan project made good use of the physical principles of thermal expansion and contraction. When the mountain pass was cut, the stone was repeatedly burned with fire, and then river water was poured over it, and the Yulei Mountain was thus successfully blasted (Guo, 2019) to make a pass with a width of about 20m, a height of 40m, and a length of 80m. This pass was named Baopingkou (Cheng & Chen, 2015).

Geomorphology - Dam-free water conservancy system

Geomorphology originated from the inquiry results of the 19th century (Woodroffe, 2001). It is the study related to topography and its formation process, and a multidisciplinary field closely related to geography and geoscience (Sack & Orme, 2013). Its science covers terrain structure, rivers, floods, groundwater, climate, and so on, but as early as 2,000 years before the formation of the geomorphology theory, Dujiangyan planned the weiring project based on the characteristics of the Minjiang River and the local terrain, and planned the first dam-free water conservancy engineering system with the least damage to the natural ecology (i.e., the first system of its kind in China). Based on this, even if Dujiangyan re-planned the direction of the mainstream of the Minjiang River, it did not damage the river ecology (Mathews, 2013).

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River water dynamics

The biggest threat to water conservancy projects is the blockage of waterways caused by sediments. This problem was innovatively solved in the construction of DIS. DIS applies the spiral river bending cycle theory. In the curved channels of the inner (concave) and outer (convex) banks, vortex water will be generated. It has inertial and centrifugal forces, throwing sand and stones to the shore (Wang, 2016). More specifically, flooding in the inner river rushes directly to the Fengqiwo mountain on the opposite bank of Flying Sand Sluice. The natural spur dike formed by the mountain directly changes the direction of the water flow. With the compulsive action of the spur dike, the mainstream of the inner river rushes directly to Flying Sand Sluice on the right bank of the inner river in the center. As the larger current results in greater rushing than silting, most of the energy is not released after the forced turn of the spur dike. The deeper the current, the more difficult it is to release energy. Deep water carries huge amounts of hydro-energy together with the bed load of the section (Li & Li, 2017). Therefore, DIS carried out the two-stage sand removal task by means of crosswise swirling flow and lateral sand removal. First, it lets the surface river flow to the concave shore and the bottom river flow to the convex shore, so that most of the sand and gravel can accompany the bottom river flow to the outer river. After the sand and gravel are divided, a part of the sediment will still flow into the inner river. At this time, the curve of the Flying Sand Sluice section discharges the sediment again from the side of the river-way due to the swirling momentum (the application of centrifugal force) caused by the river water directly rushing to the bottom cliff.

Hydrology

Hydrology is a method and guide for watershed estimation, covering topics including river measurement, rainfall measurement, catchment, water flow, evaporation, transpiration and soil water content (Brandt et al., 2017). It is obvious that DIS incorporates various types of hydrological knowledge to balance the water level between the flood season and dry season of the Minjiang channel.

Technology Application in Dujiangyan

According to historical records, DIS is a low dam and dike made of local natural materials (Luo, et al., 2010), and four traditional hydraulic technologies of DIS, Bamboo-Cage, Ma-Cha, Laid-Cobblestones and Sheep-pen (Zhang, 2017), were developed and used to build the system when such building materials as reinforcing steel bars and cement had not yet been invented.

Bamboo-Cage

Bamboo-Cage is made of Phyllostachys bissetii and Neosinocalamus affinis, which are abundant in the area of the Minjiang River (see Figure 6). The cage is loaded with cobblestones to make a large cobblestone Bamboo-Cage for building Fish Mouth, Flying Sand Sluice, reinforcing the diversion dike, the spur dike, revetment, blockade, blocking of the branch of the river current, and so on (Lin & Wu, 2001). The dike is composed of long sausage-shaped bamboo-woven baskets, which are filled with stones called Zhulong (meaning bamboo dragons) (Guo, 2019). Bin Li, the original designer of the system, asked the local residents to weave bamboo into huge Bamboo-Cages, each 2 feet wide by 3 feet long. These Bamboo-Cages were filled with large stones and cobblestones, and then a large number of laborers poured them into the river. Together, they quickly built a diversion dike (Duan, 2012). The stone Bamboo-Cage, which has several times more weight than the original, can completely "resist the impulse of the water flow."

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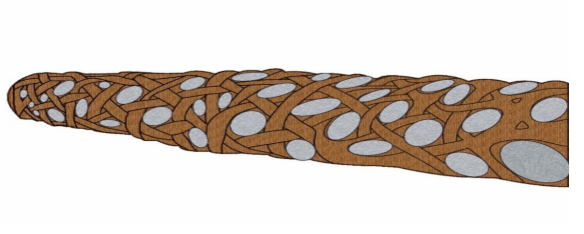
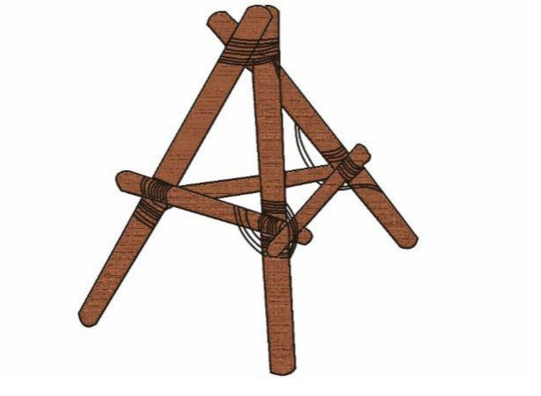
Figure 6
Bamboo-Cage



Ma-Cha

The Ma-Cha cofferdam is a hydraulic engineering technology that has been set up with bamboo, wood and cobblestones for more than 2,000 years (Kuo, 2014) (see Figure 7). Ma-Cha is used to dam the river for annual repair, to regulate flow, rescuing closure, and deflect flow for revetments (Lin & Wu, 2001). Ma-Cha is a simple low-cost structure, but it is very effective, so it has been used for more than 2,000 years (Luo et al., 2010). It is a tripod made of three pieces of wood with a diameter of about 20 to 30cm and a length of 6m to 8m bound by bamboo ropes with tripod. A cobblestone is placed in the middle as ballast. Soil is poured into the water to build the dike with the method of "increasing density layer by layer" to stabilize the upstream face of Ma-Cha.

Figure 7
Ma-Cha



Laid-Cobblestones

Stones are used as temporary dams (Luo et al., 2010). The Minjiang River cobblestones with their coarse grain size and high degree of hardness are used to build dikes, dams, overflow dams, bank revetments, and so on (see Figure 8). In order to maintain the stability of the laid dry cobblestones, each dry cobblestone is placed with the large head of the cobblestone downward and close to the cobblestones on the top, bottom, left and right sides. In order to enhance the ability of the laid dry cobblestones to resist the erosion of the water flow, the excavation depth of various engineering building foundations is also determined in consideration of the depth of the river bed that may be washed away (Lin & Wu, 2001). The dense arrangement prevents the river water from taking away a large amount of sediment to break the foundation.

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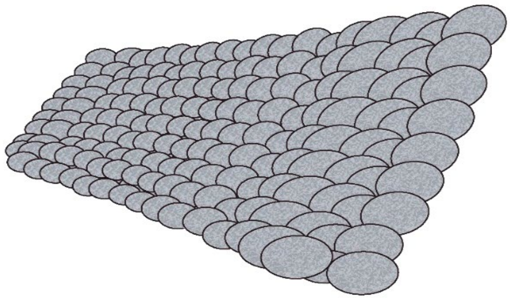
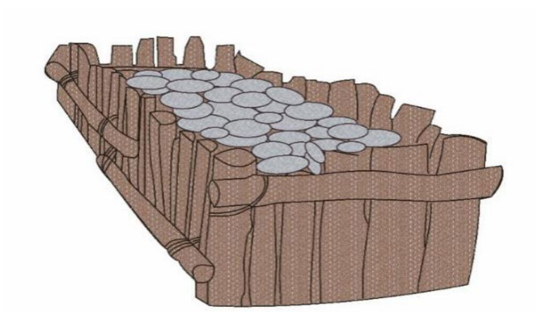
Figure 8
Laid-Cobblestones



Sheep-Pen

Cage stone technology is a basic engineering project of Dujiangyan (Yu et al., 2003). In the Fish Mouth project, four wooden columns are erected at the four corners as skeletons, and horizontal beams are connected on each side to form a large wooden frame of 3m to 4m long, which is like a Sheep-pen (see Figure 9). In ancient times, when "Fish Mouth" was built, the "Sheep-pen" was used as the base to make Fish Mouth stronger (Lin & Wu, 2001). Because the Sheep-pen is filled with large cobblestones and placed in a position subject to rapids, its arrangement can produce the effect of resisting water in rushing its top.

Figure 9
Sheep-Pen



Engineering Application in Dujiangyan

Dujiangyan's engineering setting fully makes use of the characteristics of rivers and terrains, while meeting the needs of water diversion or navigation, without changing the original geographical characteristics of the river. It operates according to local conditions, with no dam storage and no gate diversion. It conforms to nature, protecting the ecological environment, among other advantages (Wang & Wu, 2017). DIS is therefore known as one of the typical examples of sustainable development.

Moreover, DIS has a water conservancy system with multiple functions such as water transfer, flood discharge, sediment release, silt sedimentation and automatic control of irrigation water (Li & Xu, 2006), which fully reflects the essence of systems engineering. In addition, over the years, DIS has attached great importance to the management and maintenance of the project (Zhang et al., 2012). Due to the long-term challenges of flood and sand disaster prevention and control, through the implementation of section depots and the use of centrifugal force,

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the diverted streams can bring the sand to the "deeply dug riverbed" to form a "low weir" which will not cause river blockage, thus allowing the river to flow for a thousand years (Xie et al., 2018) by making the most of the optimization highlighted in the project.

Mathematical Application in Dujiangyan

Initially, Bin Li placed three stone statues at three different locations in DIS (Sun, 2008), using the most primitive tools for water level measurement with the stone statues as a benchmark (Sung & Wu, 2016) (see Figure 10). The height of the water level must be maintained above the feet of the stone statue and below the shoulders. When the water level is as high as the feet, it can meet the basic needs of irrigation waters. If the water level exceeds the shoulders, the irrigation area will face the risk of flooding (Zhou, 2015). DIS water flow is stabilized at the level below the feet when the water is insufficient, and at the level not higher than the shoulders when the water is full. It can be seen that the optimization emphasized in the project depends on mathematics for water level measurement. In addition, Ma-Cha is a tripod made of three pieces of wood with a length of 6m to 8m, which are bound by bamboo ropes (Ko & Qian, 2014). The mathematical application of the tripod is highlighted here as the tripod is more stable than a quadripod or polygon.

Figure 10
Stone Statue Simulation

Discussion

Engineering, science and technology have been a powerful driving force for the evolution of human civilization since humans learned to use tools 2.5 million years ago (Xu, 2018). The most significant concept of modern STEM education is the concept of integration, which means that STEM is a purposeful integration of various disciplines used to solve real-world problems. It can be clearly seen that this feature is reflected in DIS. DIS, through the three major interlocking engineering parts, has successfully dealt with the problem of sand and gravel deposition. It has therefore largely avoided the possibility of being destroyed by silt deposits and can serve as the foundation for sustainable ecological development (Wang et al., 2019). As can be seen in Table 1, before many academic terms were proposed, DIS was already rich in STEM educational value.

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Table 1
STEM and DIS

Item	Science	Technology	Engineering	Mathematics
Fish Mouth	1. Geomorphology 2. Hydrology	1. Applying Sheep-pens and Bamboo-Cages	1. Flood diversion control 2. Systems engineering	1. River water flow calculation
Flying Sand Sluice	1. Geomorphology 2. River dynamics 3. Hydrology	1. Application of Laid-Cobble-stones and Bamboo-Cages	1. Sand discharge mechanism 2. Systems engineering	1. River water flow calculation 2. Calculation of sand discharge
Baopingkou	1. Geomorphology 2. Hydrology 3.Applying the principle of thermal expansion and contraction to cut a mountain pass	1. Burning stones instead of gunpowder	1. River water flow control 2. Systems engineering	1. River water flow calculation
Bamboo-Cage		1. Weir tool development	1. Weight reinforcement 2. Structural stability	1. Size measurement
Ma-Cha		1. R&D of annual repair tools	1. Weight reinforcement 2. Structural stability	1. Isosceles triangle
Sheep-pen		1. Weir tool development	1 Weight reinforcement	
Laid-Cobble-stones		1. Weir tool development	1 Weight reinforcement 2. Anti-erosion 3. Structural stability	
Stone Statue		1. Water ruler tool development	1. Weight reinforcement 2. Anti-erosion	1.Measuring no.
Stone Horses (Lying Irons)		1. Water ruler tool development	1. Gravity 2. Anti-erosion	1.Measuring no.

DIS is a complex decision-making and problem-solving process that requires the application of scientific, mathematical, engineering and technical knowledge to make optimal use of resources to solve poor structure problems (Fan & Yu, 2017). From the interpretation of DIS, the integrated STEM can be found. During the construction process and subsequent implementation operations, a wide range of integrated knowledge in multiple fields has been used, but this has rarely been proposed in previous history education or science education. It can be seen from the above that most of the applications of science include the application of mathematics and physics, and it is obvious that there is a close relationship between science and mathematics. It is clear to see that Mathematics is applied in DIS, as mathematics formula should be used to calculate the proportion and symmetry, and the force of motion of the objects, and to co-control the space and objects. The results of this study are in line with Kanadlı's (2019) suggestion that STEM course design should involve at least two subject areas, and that the four knowledge domains of STEM can be integrated in future education programs. Accordingly, this study has illustrated that Bin Li applied STEM implicitly with the principles of river geology and river dynamics (e.g., erosion and sedimentation, river characteristics, river flow, etc.) to avoid the adverse effects of Dujiangyan, which has made Sichuan a "Land of Abundance" with fertile land and rich resources (Zhang, 2018).

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Conclusions

The purpose of this study was to analyze the application of STEM to the historically well-known DIS through the lens of CHAT. The structures of DIS related to cultural-historical activities provide opportunities to analyze the application of the STEM principle, such that transferring knowledge through familiar and well-known historical buildings may make learners feel more inspired. Developing cultural-historical events to support STEM in the classroom is a challenging process due to the key requirements of finding event elements and bridging them with STEM. The key findings through the descriptive-interpretative process highlight how the components of DIS illustrate the application of STEM, thus meeting the contemporary demands of STEM education and suggesting future possibilities for developing more STEM programs based on cultural-historical sites. That is, schools can arrange visits for outdoor STEM teaching which will help them to learn STEM knowledge more effectively and extensively.

Limitations and Future Studies

Although this study analyzed the educational significance of STEM in DIS from the perspective of curriculum content analysis, a detailed curriculum has not yet been implemented. Therefore, the specific teaching results of applying STEM from DIS to explore the effect is unknown. Hence, in subsequent research, the effectiveness of learning STEM via studying DIS can be evaluated by implementing different teaching approaches.

The history of civil projects is as old as human life itself and can be explained by observing ancient constructions (Kamal & Arshid, 2016). For example, the Great Wall of China was built over the period from the Western Zhou Dynasty to the Ming Dynasty, with a construction period of more than 2,000 years, and it extended 100,000 kilometers, demonstrating the remarkable achievements of ancient STEM (Xu, 2018). Therefore, it is suggested that the many cultural-historical projects can be analyzed in the future to explore the application of STEM, such as the Great Wall of China, the Forbidden City of Beijing, and the Beijing-Hangzhou Grand Canal in China, as well as structures from other ancient civilizations, such as the pyramids of Egypt and Peru.

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