Volume 23
Number 02
August, 2024

SIEF

science insights education frontiers

pISSN: 2644-058X eISSN: 2578-9813

Published Monthly by
Insights Publisher

Science Insights Education Frontiers

pISSN 2644-058X
eISSN 2578-9813
(Monthly)

Volume 23, No. 2

August 2024

Insights Publisher

Science Insights Education Frontiers

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Science Insights Education Frontiers

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eISSN 2578-9813

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COMMENTARY

Infusing the Engineer Design Process into Education

Longjun Zhou

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"Engineering is the closest thing to magic that exists in the world."
–Elon Musk

THE ENGINEERING design process (EDP) is an iterative decision-making process, in which basic science, math, and engineering concepts are applied to develop optimal solutions to meet an established objective (Mangold & Robinson, 2013). There is no unitary standard for the EDP, and researchers have different ideas about the basic steps that should be included in the process. In practice, the EDP may varies by discipline and project, but it's essential features typically include: (1) starting with the definition of the problem or needs; (2) being open-ended with multiple possible solutions; (3) involving mathematical modeling and scientific analysis; (4) being highly iterative (Atman et al., 2007; Hynes, 2012; Berland et al., 2014).

The EDP is not only applied in the domain of engineering but is also a useful tool applicable at all levels of education. It can provide students with an opportunity to learn scientific knowledge in a real-world scenario (Berland et al., 2014) while also contributing to developing their schema of design thinking, especially with respect to clarifying the problem, generating ideas, modeling, and feasibility analysis (Lin et al., 2021). With the increased awareness of the significance of the EDP as a pedagogical strategy, educators began to experiment with it in K-12 engineering teaching to promote the development of 21st century skills in students. For example, the University of California, Berkeley launched the ADEPT (Applied Design Engineering Project Teams) program to design and deploy standards-based engineering curriculum for middle and high school students (in grades 6-12). The program was designed to integrate mathematics and science concepts applied in engineering projects to inspire secondary students, helping them succeed in relevant subjects, and to strengthen the classroom experience of current and future teaching staff in math, science, and engineering (Mangold & Robinson, 2013). Earlier research found certain challenges of the use of the EDP in instruction including students' neglect of its quantitative aspects, such as quantifying needs, establishing structured methods to reach solutions, and developing mathematical models (Crismond & Adams, 2012; Berland et al., 2014). To address these issues, teachers needed to design special contexts and questions to engage students in the quantitative work of the design process. However, it does not mean the qualitative content of the EDP, such as identifying problems and modifying solutions, is less important. Instead, these aspects of the EDP allow students the perception of steady progress as they are more manipulable and familiar to learners (Barnett, 2005; Hmelo et al., 2000).

In recent years, the alignment between the EDP's application outcomes and the objectives of STEM education has inspired researchers to incorporate the EDP into the latter, such as 3D printing education (Hou, 2019). Some researchers asserted that the EDP was integral to STEM teaching and highlighted the three requirements for designing EDP-based STEM education programs: adhering to student-centeredness; linking the problem or task to the actual life of students; and adopting the formative assessment to document students' learning process and encourage reflections on learning outcomes (Zhang et al., 2019). Other researchers tried to combine the EDP with STEM project-based learning to create the more sophisticated model of EDP-STEM-PBL. This model seeks to situates scientific and mathematical knowledge within the context of technological design to build a problem-solving learning environment which facilitates students formulating solutions to design challenges, gathering information, and solving real problems using the EDP (Lin et al., 2021).

Despite the validations of the positive effects of the integration of the EDP into STEM education in the literature (Hafiz & Ayop, 2019), insufficient is the research on applicable strategies for the design and implementation of EDP-based curricula, and studies of localized EDP application are even fewer. In this issue, *Engineering Design-Based STEM Activity for Middle Schools: How Can I Slide Faster?* is a study of the design and implementation of an EDP-based STEM education activity for the instruction of "friction force and water resistance" based on the US's Next Generation Science Standards (NGSS) and the objectives and outcomes set for the 5th-grade science curriculum by the Turkish Ministry of National Education. Twenty-one Turkish students in grade 5 participated in the study, who were required to design a water slide boat that would be least affected by water resistance and friction (Gökşena et al., 2024). The activity was meant to improve students' engineering and design skills. Despite its elaboration on the design and implementation steps of EDP-based STEM education activity, there was no quantitative analysis of students' learning outcomes in the study, resulting in the lack of an objective and explicit demonstration of the activity's effectiveness. Still, the research findings of this study can provide valuable guidance to science teachers for their practices of integrating the EDP into the design and implementation of STEM teaching activities. It is hoped that these findings can spark explorations of the application of the EDP in a more extensive range of disciplines.

References

Atman, C. J., Adams, R. S., Cardella, M. E., Turns, J., Mosborg, S., & Saleem, J. (2007). Engineering design processes: A comparison of students and expert practitioners. *Journal of Engineering Education*, 96(4):359-379. DOI: https://doi.org/10.1002/j.2168-9830.2007.tb00945.x

Barnett, M. (2005). Engaging inner city students in learning through designing remote operated vehicles. *Journal of Science Education and Technology*, 14:87-100. DOI: https://doi.org/10.1007/s10956-005-2736-z

Berland, L., Steingut, R., & Ko, P. (2014). High school student perceptions of the utility of the engineering design process: Creating opportunities to engage in engineering practices and apply math and science content. *Journal of Science Education and Technology*, 23:705-720. DOI: https://doi.org/10.1007/s10956-014-9498-4

Crismond, D. P., & Adams, R. S. (2012). The informed design teaching & learning matrix. *Journal of Engineering Education*, 101(4):738-797. DOI: https://doi.org/10.1002/j.2168-9830.2012.tb01127.x

Gökşena, O., Kızılay, E., Oktay, O., & Önalc, N. T. (2024). Engineering design-based stem activity for middle schools: How can I slide faster? *Science Insights Education Frontiers*, 23(2):3733-3753. DOI: https://doi.org/10.15354/sief.24.or612

Hafiz, N. R. M., & Ayop, S. K. (2019). Engineering design process in stem education: A systematic review. *International Journal of Academic Research in Business and Social Sciences*, 9(5):676-697. DOI: https://doi.org/10.6007/IJARBSS/v9-i5/5998

Hmelo, C. E., Holton, D. L., & Kolodner, J. L. (2014). Designing to learn about complex systems. In Design Education (pp. 247-298). Routledge.

Hou, J. (2019). 3D printing instruction based on the engineering design process. *Afterschool Education in China*, 2019(34):110-111.

Hynes, M. M. (2012). Middle-school teachers' understanding and teaching of the engineering design process: A look at subject matter and pedagogical content knowledge. *International Journal of Technology and Design Education*, 22:345-360. https://doi.org/10.1007/s10798-010-9142-4

Lin, K. Y., Wu, Y. T., Hsu, Y. T., & Williams, P. J. (2021). Effects of infusing the engineering design process into STEM project-based learning to develop preservice technology teachers' engineering design thinking. *International Journal of STEM Education*, 8:1-15. DOI: https://doi.org/10.1186/s40594-020-00258-9

Mangold, J., & Robinson, S. (2013). The engineering design process as a problem solving and learning tool in K-12 classrooms. 2013 ASEE Annual Conference & Exposition. DOI: https://doi.org/10.18260/1-2--22581

Wahono, B., Lin, P. L., & Chang, C. Y. (2020). Evidence of STEM enactment effectiveness in Asian student learning outcomes. *International Journal of STEM Education*, 7:36. DOI: https://doi.org/10.1186/s40594-020-00236-1

Zhang, H., Lin, J., & Zhu, L. (2019). Comparative analysis of the scientific inquiry process, engineering design process, and STEM process. *Educational Information Technology*, 2019(6):54-57.

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Conflict of Interests: *None*

Doi: *10.15354/sief.24.co335*

COMMENTARY

Developing Principal Leadership Assessment Instruments: The Necessity and Challenges

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"I can respect any person who can put their ego aside and say, I made a mistake, I apologize, and I am correcting the behavior."
–Sylvester McNutt

PRINCIPAL leadership evaluation and assessment, one of the crucial means for managing and monitoring principals, is of vital significance for principal professional development, the enhancement of principal leadership capability, the optimization of the principal accountability system, and school improvement (Wang, 2016; Han, 2019). At the level of personal growth, principal leadership assessment can provide school leaders with formative and summative feedback, which is beneficial for their professional development (Murphy et al., 2011). At the level of school management, it helps the principal identify the gaps between the existing practices and expected outcomes to make informed decisions for school improvement and development (Goldring et al., 2009); in the meantime, principal leadership assessment with definite results enables other school administrators to understand clearly the goals set for the school and principal, contributing to the development of a climate of collective accountability (Murphy et al., 2011) and the improvement of school governance. Overall, well-designed and properly implemented principal leadership assessment can effectively enhance organizational performance and help select qualified school leaders (Murphy et al., 2011).

The development of effective principal leadership assessment instruments was initiated in the 1980s. The Principal Instructional Management Rating Scale (PIMRS) by Hallinger and Murphy (1985) and the Vanderbilt Assessment of Leadership in Education (VAL-ED) by Porter et al. (2008) are the best-known among them. The PIMRS assesses the effectiveness of principal leadership behaviors in three dimensions: defining the school mission, managing the instructional program, and developing a positive school learning climate (Hollinger & Murphy, 1985). In the past 40 years or so, the scale has been widely used and examined by researchers and is deemed a reliable instrument for assessing principal leadership. Yet, it has its limitations with its neglect of the contextual variables of the school and the role of teachers' agency (Hollinger, 2003). The VAL-ED is a learning-centered, 360-degree assessment, focusing on school leadership that improves student academic achievement. The assessment is based on a conceptual framework of six core components and six key processes. The core components include high standards for student learning, rigorous curriculum (content), quality instruction (pedagogy), culture of learning and professional behavior, connections to external communities, and performance accountability. The key processes are behaviors that principals can employ to enact the six core components: planning, implementing, supporting, advocating, communicating, and monitoring (Porter et al., 2008). Contrary to the said two assessments based on principal positive behaviors, Burkett (2020) adopted an inverse approach and developed the Principal Effectiveness Assessment Kit (PEAK) by looking at traits that define ineffective principal leadership. This instrument assesses the state of a principal's leadership by five key themes relevant to ineffective principal leadership including a lack of professionalism and ethics, limited leadership skills, lack of teacher and student advocacy, limited listening and communication skills, and a poor school culture and climate. However, the U.S. education context of the aforementioned assessment instruments may constrain their usage in other countries. Many researchers have sought to create localized principal leadership assessments in line with the circumstances of their own countries. For instance, Brown and Chai (2012) developed the Self-Assessment of Leadership of Teaching and Learning (SALTAL) according to New Zealand education needs, which evaluate principal leadership in the following dimensions: knowledge and skills for leading teaching and learning; commitment to ensuring positive learning outcomes for all students; collaborative leadership; and ethical leadership.

Despite the multiple instruments designed for advancing school leadership evaluation, various challenges emerged in their implementation practices. Some researchers noted the bias in the purpose of current assessments that emphasize leadership discipline over school improvement as well as the ambiguity of assessment focus - on principal or school performance (Wang, 2016). Moreover, the majority of these assessments are self-report evaluations (Brown & Chai, 2012), leading to their lack of objectivity. This is because, compared with the third-party observation or external evaluation, the self-evaluation is subject to biases such as self-enhancing tendencies (e.g. not reporting aspects which make the evaluator feels bad about the evaluatee) and social desirability tendencies (Donaldson & Grant-Vallone, 2002), compromising the effectiveness of assessment.

For further exploration of more reliable and effective principal leadership assessment instruments, it is of critical importance to identify core elements of principal leadership. *Essential Elements of Principal Leadership: A Literature Review of Leadership Qualities of Primary and Secondary Principals* in this issue is a systematic survey on key leadership qualities of primary and secondary principals based on a review of 60 journal articles in English and Chinese. These qualities, summarized in the dimensions of personal traits, the capacity to influence people, and the ability to make sustainable organizational improvements, are subject to little geographical and temporal influence, representing general expectations and requirements for basic education school principals from the global education world (Chen & Chen, 2024). While this study has provided a qualitative lens for understanding principal leadership, the issue of how to establish a scientific, quantitative assessment framework for more accurately gauging the principal's leadership capacity is pending further research. Furthermore, the literature drawn on by this survey includes both qualitative and quantitative studies, which give us different perspectives for probing leadership qualities. Nevertheless, certain amounts of prudence and careful discrimination are necessitated when incorporating their research results in the creation of principal leadership assessment scales since those qualitative studies contain the researchers' subjective interpretations and personal experience, which may undermine the validity and objectivity of the scale in development.

References

Brown, G. T. & Chai, C. (2012). Assessing instructional leadership: A longitudinal study of new principals. *Journal of Educational Administration*, 50(6):753-772. DOI: http://doi.org/10.1108/09578231211264676

Burkett, J. (2020). Ineffective campus leadership: Why teachers leave bad principals. *Journal of Academic Perspectives*. 2020(4).

Chen, X. & Chen, H. (2024). Essential elements of principal leadership: A literature review of leadership qualities of primary and secondary principals. *Science Insights Education Frontiers*, 23(2):3811-3825. DOI: https://doi.org/10.15354/sief.24.re392

Donaldson, S. I. & Grant-Vallone, E. J. (2002). Understanding self-report bias in organizational behavior research. *Journal of Business and Psychology*, 17(02): 245-260. DOI: https://doi.org/10.1023/A:1019637632584

Goldring, E., Cravens, X. C., Murphy, J., Porter, A. C., Elliott, S. N., & Carson, B. (2009). The evaluation of principals: What and how do states and urban districts assess leadership? *The Elementary School Journal*, 110(1):19-39. Available at: http://www.jstor.org/stable/10.1086/598841

Hallinger, P. (2003). Leading educational change: Reflections on the practice of instructional and transformational leadership. *Cambridge Journal of Education*, 33(3):329-351. DOI: https://doi.org/10.1080/0305764032000122005

Hallinger, P. & Murphy, J. (1985) Assessing the Instructional Management Behaviour of Principals. *The Elementary School Journal*, 86:217-247. DOI: http://doi.org/10.1086/461445

Han, Y. (2019). Principal leadership evaluation research: The current state and new prospects. *Education Modernization*, 6(58):180-181. DOI: https://doi.org/10.16541/j.cnki. 2095-8420.2019.58.083

Murphy, J., Goldring, E., Elliott, S., Cravens, X., & Porter, A. (2011). Vanderbilt assessment of leadership in education: A learning-centered assessment approach. *Journal of East China Normal University (Education Science Edition)*, 2011(1):1-10. DOI: https://doi.org/10.16382/j.cnki.1000-5560.2011.01.008

Porter, A., Goldring, E., Elliott, S., Murphy, J., Polikoff, M., & Cravens, X. (2008). Setting Performance Standards for the VAL-ED: Assessment of Principal Leadership. Online Submission.

Wang, J. (2016). A professional standards-based principal leadership evaluation framework. *Research in Educational Development*, 2016(4):64-70. DOI: https://doi.org/10.14121/j.cnki.1008-3855.2016.04.012

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***Conflict of Interests**: None*

***Doi:** 10.15354/sief.24.co338*

ORIGINAL ARTICLE

Engineering Design-Based STEM Activity for Middle Schools: How Can I Slide Faster?

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***Abstract**: In the current study, an engineering design-based STEM activity was designed and implemented for 5th graders. The current activity is expected to provide guidance and perspective to teachers (practitioners) in designing and implementing an activity based on design-based learning, STEM activity, and engineering design process (EDP). At the same time, during the implementation of the activity, teachers and students experienced a STEM activity based on the EDP. In the fall semester of the 2022-2023 academic year, this STEM activity based on the engineering design process was planned for Friction force and water resistance in the 5th-grade middle school science course. Then, the activity was implemented in a class of 21 students. The activity was implemented in three class hours. This activity, titled "Let's Design a Water Slide Boat," aimed at designing a water slide boat that would be least affected by water resistance and friction force to improve students' engineering and design skills. This activity was based on NGSS and the objectives and outcomes set in the 5th-grade science curriculum of the Turkish Ministry of National Education.*

Science Insights Education Frontiers 2024; 23(2):3733-3753
DOI: 10.15354/sief.24.or612

How to Cite: Gökşena, O., Kızılay, E., Oktay, O., & Önalc, N. T. (2024). Engineering design-based stem activity for middle schools: How can I slide faster? Science Insights Education Frontiers, 23(2):3733-3753.

***Keywords**: STEM Activity, Engineering Design Process, STEM Education*

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***Conflict of Interests**: None*

***AI Declaration**: The authors affirm that artificial intelligence did not contribute to the process of preparing the work.*

Introduction

THE PRIMARY objective of education should be to raise people with the so-called 21st-century skills, which are becoming more and more crucial day by day. These skills include innovation, design thinking, entrepreneurship, questioning, teamwork, analytical skills, and science and technology literacy (Aranda et al., 2020). Design-based learning (DBL) is essential to achieving this objective. DBL can be described as a teaching strategy incorporating content knowledge into the creative production process so that students design artifacts to address real-world issues with Papert's theory of constructionism (Doppelt et al., 2008). Through DBL, it may be possible to teach science to students, provide motivation, and guide students toward engineering careers (Chandrasekaran et al., 2013).

The engineering design process is used in DBL, as is evident from this (Dopplet & Barak, 2021). Engineering Design Process (EDP) is defined as a set of processes that includes the steps of selecting the best way to solve a problem, conducting research, and creating products (National Research Council [NRC], 2009). In its most basic sense, the engineering design process is the set of ways engineers solve problems. Engineering design is also characterized as an essential teaching-learning tool for developing skills such as open-ended problem-solving, creative thinking, solution generation, decision-making, and evaluation of alternative solutions (Wang et al., 2013). As can be inferred, some steps in the engineering design process are also found in science and technology. In addition, the fields of science and engineering mutually feed each other (Next Generation Science Standards [NGSS], 2013; NRC, 2012). At this point, for quality education, it is recommended that the scientific research inquiry process and the engineering/technology design process should operate together in the learning process (NRC, 2012). The focus of STEM education, which is based on integrating science, technology, engineering, and mathematics (STEM) disciplines, is also to enable students to integrate scientific knowledge and practices using real-life engineering problem-solving and creative design processes (Lou et al., 2014). From this perspective, combining the content knowledge of science and engineering disciplines with science and engineering practices is essential, thereby increasing students' knowledge and skill levels. To achieve this, students are expected to solve engineering problems in a real-life context within the framework of a specific theme they are confronted with (NRC, 2012). There are different variations of the EDP. For this reason, it is more important to focus on the standard components in the variations, such as defining the problem, setting the criteria for solving the problem, realizing prototype designs, and finding the best solution (NGSS, 2013). In EDP, a cyclical process, the solution to the problem is either a model (design-prototype) or a modeling (Hynes et al., 2011; NRC, 2012).

EDP education contributes to students' academic achievement (Mehalik et al., 2008), transfer of knowledge to real life (Thomas, 2014), and development of 21st-century skills (Bybee, 2010; Stehle & Peters Burton, 2019). It positively affects learners' interest, attitude, and motivation toward STEM disciplines and develops their career awareness (Baran et al., 2015; Christensen & Knezek, 2017). As a result, individuals who have acquired design skills are expected to be able to solve the problems they face in daily life, think innovatively and creatively, be self-confident, entrepreneurial, and technologically literate, and pursue careers in scientific fields (Bybee, 2010). Despite all this importance, traditional classroom environments must be improved regarding design activities. Learners need to be provided with design skills and, thus, the ability to solve design problems they may encounter in real life (Moreno et al., 2016).

On the other hand, science instruction is a complex process, and students typically need to improve in science (Fokides & Papoutsi, 2020). Considering this situation, the EDP-based science education process comes to the forefront to improve the quality of science education, which is closely related to science, technology, and society and whose nature overlaps with the process of engineering and scientific research, and to build a society of science learners with developed 21st-century skills. Indeed, NRC (2012) emphasizes the components of science education, such as developing science literacy, problem-solving, and engineering skills, and conducting research with scientific ethics.

When the literature is examined, it is clear that there are numerous studies on designing and adapting engineering design-based activities on friction force for teachers (Hacıoğlu, 2020), designing activities for children in their early years (Ata Aktürk, 2023; Tanık Önal & Saylan Kırmızıgül, 2021) and high school students (Baptista & Martins, 2023). Applied studies in the field of STEM in the literature are generally conducted with the participation of pre-service science teachers (Buber & Unal Coban, 2020) and middle school students (Wieselmann et al., 2020).

In our study, a STEM activity about water resistance and friction force was designed for 5th graders based on the EDP. The selection of 5th graders in our study is essential. Studies examine the effect of STEM-based activities integrated with the 5th-grade science course content on students' problem-solving skills and academic achievement. For example, the article by İnce et al. (2018) investigated how integrating STEM-based activities with science course content affected students' problem-solving skills and academic achievement related to the earth's crust. The results showed a significant increase in students' problem-solving skills and academic achievement in STEM-based activities. The study conducted by Eker (2020) examined the effect of STEM activities prepared based on the 'Measurement of Force and Friction' and 'Matter and Change' units in science courses on students' motivation and entrepreneurship. The results showed that the teaching method supported by STEM activities increased students' motivation but did not provide a statistically significant increase in entrepreneurship skills. Keçeci et al. (2017) examined students' attitudes and emotions toward coding learning through STEM education practices consisting of guided inquiry, inquiry-based science activities, coding education, and educational game-supported coding learning. The results showed a significant increase in attitude towards coding learning supported by educational computer games and that students found the science activities enjoyable. Some even preferred to experience them again with their families. In conclusion, designing an EDP-based STEM activity about water resistance and friction force for 5th grade students is of great importance for students to gain experience in the STEM field and develop their problem-solving skills. Such activities can increase students' motivation and academic achievement by providing them with more in-depth knowledge in the fields of science, technology, engineering, and mathematics. Kahveci (2020) analyzed the science textbooks in Türkiye in terms of STEM criteria and found that the activities in the 5th-grade textbook partially met the necessary criteria, and most of the activities for science, engineering, and entrepreneurship practices in the textbooks of other grades did not meet the criteria. This is important because students have experienced STEM activities based on EDP before.

According to studies conducted in Türkiye, STEM education textbooks are inadequate, and even though teachers want to implement STEM activities, they encounter challenges (in terms of the practitioner's competencies, the availability of materials, and cooperation), which makes them hesitant (Özbilen, 2018). Again, according to the literature, teachers have difficulty presenting problems that will enable students to make interdisciplinary connections and carry out the research process (Diana, 2021). With this in mind, it can be said that there is a need for STEM activities to spread throughout society, particularly in Türkiye, and for practitioners to develop their skills and knowledge.

This study aims to design and implement an engineering design-based STEM activity for fifth-grade students. This activity is expected to guide teachers (practitioners) in developing and implementing an activity based on design-based learning, STEM activity, and EDP (Engineering Design Process). At the same time, during the implementation of the activity, teachers and students will experience a STEM activity based on EDP. For these purposes, the research questions are as follows:

- How can an engineering design-based STEM activity be designed and implemented for fifth-grade students?

- How can this activity provide guidance and perspective to teachers in designing and implementing an activity based on design-based learning, STEM activity, and EDP?
- Can teachers and students experience a STEM activity based on EDP during its implementation?

Method

In the fall semester of the 2022-2023 academic year, this STEM activity based on the engineering design process was planned for Friction force and water resistance in the 5th-grade middle school science course. Then, the activity was implemented in a class of 21 students (11 girls and 10 boys). The activity was implemented in three class hours (40+40+40+40 minutes).

This activity, titled "Let's Design a Water Slide Boat," aimed to design a water slide boat that would be least affected by water resistance and friction force to improve students' engineering and design skills. This activity was based on NGSS (2017) and the objectives and outcomes set in the 5th-grade science curriculum of the Turkish Ministry of National Education (MoNE, 2018) (**Appendix 1**). At the end of the activity, students are expected to achieve the following STEM acquisitions.

STEM Acquisitions

- Gives real-world illustrations of friction force.
- Generates new ideas to increase or decrease friction in daily life.
- Defines a daily life problem.
- Creates ideas for solving the problem.
- Draws various designs for the solution of the problem.
- Identifies the limitations of their designs.
- Creates the design (prototype).
- Tests the design.
- Improves the design.

The activity was planned based on NASA's (2011) engineering design cycle. According to this cycle, the steps of asking questions, imagining, planning, creating, testing, and improving follow each other cyclically. Before the activity, the students were informed about this cyclical process.

Ethics Rules Taken into Account in the Study

In this activity design and implementation study, the whole process was explained in detail to ensure the transferability of the research. In addition, after the activity was designed, two field experts were consulted to evaluate the activity. These evaluations focused on qualities such as the appropriateness of the activity for the grade level, whether it meets the outcomes, its suitability for the duration, the appropriateness of the activity for the execution of EDP, the suitability of the problem situation for STEM education, and finally the examination of the boundaries of the design task to be carried out to solve the problem. Expert opinions were that the activity design had no implementation deficiencies. Then, the implementation started. A volunteer teacher implemented the activity. Necessary precautions were taken to prevent the teacher and students from being recognized in the photographs presented in the study.

Activity: Design a Water Slide Boat

Skills Based on the Activity

Scientific Process Skills

Measuring, recording data, hypothesizing, using data and modeling, changing and controlling variables, and experimenting.

21st Century Skills

Analytical thinking, decision making, creative thinking, communication, teamwork, entrepreneurship.

Engineering and Design Skills

Innovative thinking, product creation, and approaching the problem from a different perspective.

Equipment/Material (Table 1)

The Connections of the Activity to NGSS

The design of the activity also took the Next Generation Science Standards (NGSS) into consideration. **Table 2** lists the NGSS that are relevant to the activity. The activity is closely related to three K-12 Science Education Framework elements, as stated in **Table 2**.

Implementation of the Activity

Table 1. Equipment and Material Prices.

Needle (1 for 1 TL)	Eva (1 for 2 TL)
Scissors (5 TL each)	Yarn (1 meter 1 TL)
Paper (1 TL for five)	Cotton (8 TL for 50 g)
Waste materials (Free of charge - It makes students care about recycling)	Chenille (1 TL each)
Ruler (5 TL each)	Eva (1 TL each)
Pencil (1TL each)	Wooden ice cream sticks (50 kr. each)
Glue (5 TL for a tube)	Tape (5 TL for a roll)
Silicone gun (50 TL for one) (Silicone gun will be used under teacher control)	Thin silicone (2 TL for 1)

Table 2. The Connections of the Activity to NGSS (NGSS, 2017).

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
• Planning and Carrying Out Investigations • Analyzing and Interpreting Data • Constructing Explanations and Designing Solutions • Obtaining, Evaluating, and Communicating Information	PS2.A: Forces and Motion • Pushes and pulls can have different strengths and directions. • Pushing or pulling on an object can change the speed or direction of its motion and can start or stop it. PS2.B: Types of Interactions • When objects touch or collide, they push on one another and can change motion. PS3.C: Relationship Between Energy and Forces • A bigger push or pull makes things speed up or slow down more quickly. ETS1.A: Defining Engineering Problems • A situation that people want to change or create can be approached as a problem to be solved through engineering. Such problems may have many acceptable solutions.	Cause and Effect • Simple tests can be designed to gather evidence to support or refute student ideas about causes.

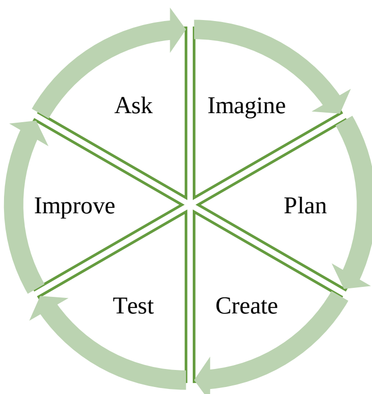

Figure 1. The Engineering Design Process by NASA (2011).

The activity was planned based on NASA's (2011) engineering design cycle. According to this cycle, the steps of asking questions, imagining, planning, creating, testing, and improving follow each other cyclically (**Figure 1**).

Ask a Question: (15min)

This activity phase aims to develop students' ability to find solutions to the problems they encounter in daily life. The problems presented to the students were designed to reveal their prior knowledge and draw their attention to the topic. Then, the questions posed by the teacher to the students were intended to stimulate their thinking abilities and problem-solving skills. The students' answers show their ability to analyze the problem situation, generate possible solutions, and share similar experiences. This activity aims to develop students' critical thinking and creative solution-finding skills**.**

First, the daily life problem shown in **Figure 2**, which was prepared by the teacher to reveal the students' prior knowledge and draw their attention to the topic, was presented.

After the students read the problem situation, the teacher asked the following questions to the students.

- What do you suppose Mert's inability to move quickly down the slide could be?
- If you were in Mert's shoes, what would you do to make it easier for him to slide?
- Did anyone ever have a similar problem while sliding down the slide before? (If so, how did you solve the problem?)

The answers given by the students to the questions are summarized as follows:

The students stated that the reasons for Mert's inability to slide fast down the slide could be that the slide was rough, the child's shorts, the friction were too much, and the child's body prevented him from sliding.

Students responded to the question *"If you were Mert, what would you do to slide more easily?"* with responses like "I would wear smoother shorts." "I would slide on a bagel." "I would slide with a plastic bag." and "I would foam my body."

In addition, in response to the question *"Has anyone ever experienced a similar problem while sliding down a water slide before? (If so, how did you solve the problem?)",* students answered, "We have never been on a water slide before, so we have not experienced such a problem.", "No, we have not experienced such an incident.", "We have not been on a water slide before, so we have not experienced such an incident.'' and ''We have not been on a water slide before, but I was wearing shorts while sliding in the park and my legs were sweaty and stuck to the slide and I had difficulty sliding. So, I slid by putting cardboard under me."

DESIGN TASK

How Can I Slide Faster?

Mert has been dreaming of a nice vacation all year and finally summer vacation has arrived. Mert likes to spend most of his time at the water slides in the hotel pool and he is very excited to slide down the water slide. At his first slide, Mert doesn't enjoy it very much because he slides very slowly, and it hurts a little.

Figure 2. Design Task.

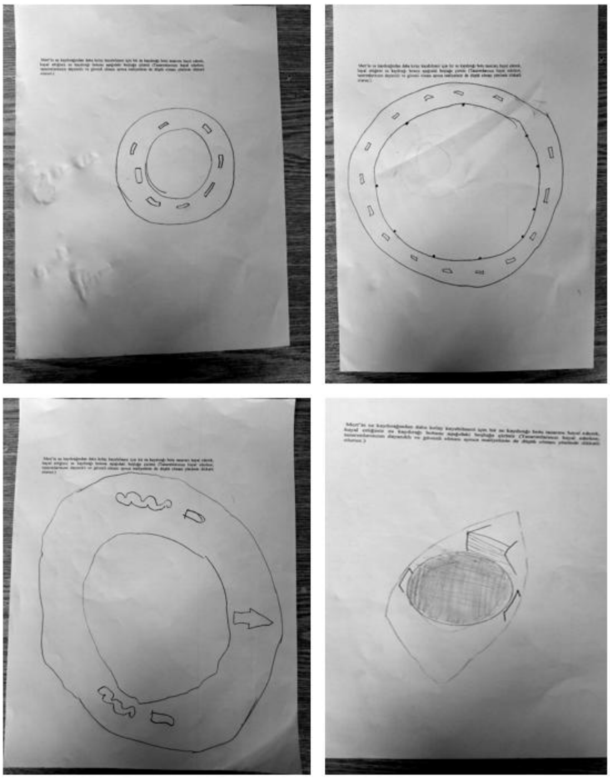

Figure 3. Design Sketches.

Imagine: (15min)

At this stage, students were divided into groups of four or five. Each group was asked to imagine a water slide boat design so that Mert could slide down the slide more easily. While the groups were imagining their designs, they were asked to be careful that their designs should be durable, safe, and cost-effective.

Plan: (20min)

The teams created design drawings by sketching out their envisioned creations on paper (**Figure 3**). They tried to keep the cost of the materials they would use in their designs low. This stage allows students to concretize their design and turn it into a practical plan.

Create: (40min)

The groups created their designs in line with the drawing they planned and designed (**Figure 4**). They wrote down the costs of their designs on a piece of paper (**Figure 5**). This activity phase aims to create designs in groups using the drawings designed by the participants and determine the costs of these designs. In the next step of the design process, the groups will do their best to turn their planned drawings into reality. This stage in the design process enables participants to fulfill a specific task by utilizing their creativity and problem-solving abilities. Also, determining costs helps participants develop their budget management skills and use of resources effectively. This stage represents a practical and hands-on dimension of the design process, enabling participants to transform their conceptual ideas into concrete products while developing their economic thinking skills.

Test: (15min)

At this stage, the designs made by the groups were tested on the slide prepared by the teacher (**Figure 6**). The groups examined their designs for the easiest and fastest way to slide. This activity phase aims to test how effective the designs prepared by the groups are in practice. The groups test their designs on the slide they have prepared. This testing process provides an opportunity to see how the designs work in real-world conditions. Groups evaluate the performance of their designs as they try to determine that their design is the easiest and fastest way down the slide. This stage allows students to experience the practical application of the design process and provides an opportunity to evaluate how well their designs function in real life. In this way, students can develop and improve their designs and, at the same time, develop their engineering and problem-solving skills. This stage allows students to test and evaluate their designs in a real-world context, allowing them to apply the scientific method and engineering principles.

Improve: (15min)

Slow and difficult sliding designs were identified, and the groups finalized the designs by eliminating the faulty aspects.

Figure 4. Examples of Design Studies.

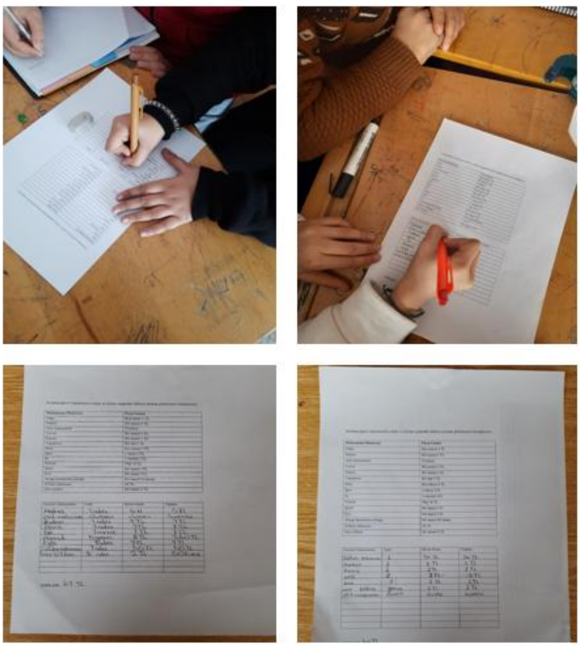

Figure 5. Design Costs.

Figure 6. Testing of the Designs.

Table 3. Design Evaluation Rubric.

Criteria	Points		
Cost of Design	Less than 60 TL 30 points	Between 60-70 TL 20 points	More than 70 TL 10 points
Time to finish the course	Less than 3 seconds 30 points	Between 3-5 seconds 20 points	More than 5 seconds 10 points
Safety	The doll is not hit and does not fall off the boat. 30 points	The doll was hit left and right but the boat did not tip over. 20 points	The boat overturned and the doll was thrown. 10 points
Resilience	It is not affected by liquid in any way. 30 points	The shape is changed by the liquid, but it still functions. 20 points	The shape is completely distorted by the liquid. 10 points

Table 4. Evaluation Rubric for Group Work.

Stages	Performance Level 1	Performance Level 2	Performance Level 3	Performance Level 4
Planning of the Design				
Teamwork	No task distribution was made before starting the design. At the same time, no definition of the needs of the design was made by the group members.	Before starting the design, all tasks were allocated without considering the wishes and skills of the people involved. At the same time, no definition of the needs of the design was made by these people.	Before starting the design, all tasks were allocated without considering the wishes and skills of the people involved. But the needs of the design were defined by these people.	Before starting the design, all tasks were allocated according to the wishes and skills of the people involved. The needs of the design were also defined by these people.
Originality of Design	No discussion was held as a group about how the design should be and no decision was taken about the design.	The group discussed how the design should be, but an original design was not decided on until the end of the process. At the same time, this design was not adopted until the end of the process.	The group discussed how the design should be, but did not decide on an original design until the end of the process. This design was adopted until the end of the process.	The group discussed how the design should be and an original design was adopted.
Drawing Related to Design	No drawing was realized that was suitable for the activity and whose draft could be transformed into a design.	A drawing was made that was not suitable for the event, but the sketch could be turned into a design.	A drawing was made that was in line with the purpose of the event but whose outline could not be turned into a design.	A drawing was made in accordance with the purpose of the event, the outline of which could be transformed into a design.
Making the Design				
Using Materials and Time Effectively	Water-resistant materials were not used for the design and the design could not be completed within the specified time.	Water-resistant materials were used for the design, but the design could not be completed within the specified time.	Water-resistant materials were not used for the design, but it was completed within the specified timeframe.	Water-resistant materials were used for the design and the design was completed within the specified time.
Effective management of the design process	The design was not maintained and managed within the control of the group as a whole or any of its members.	Not all group members were involved in the design and the design was controlled and managed only by one of the group members.	The design was led by only one individual, although it was maintained within the control of all group members.	The design was sustained and managed within the control of all group members.
Cooperation Ability Among Stakeholders	During the design process, there was not a good collaboration between all group members and consequently the workload could not be organized in a controlled manner.	During the design process, it is often the case that all group members failed to cooperate and workload is undertaken by some individuals in the group.	During the design process there was cooperation among all group members intermittently and during these cooperation intervals individuals in the group shared workload equally.	During the design process, there was always cooperation among all group members and the whole group individuals shared workload equally.
Testing the Design and	The design was not tested for its intended purpose at	The intended design was not pursued, and although the	The intended design was not abandoned, and	The intended design was not abandoned, and

Improvement	any point in the process and ideas and solutions for its improvement were not developed.	design was tested intermittently for its intended purpose, no new ideas and solutions were developed.	although it was constantly tested for its intended purpose, no new ideas or solutions were developed.	the design was continuously tested for its intended purpose and new ideas and solutions were developed.
Taking Security Measures	No safety precautions were taken for the storage and use of the materials and no responsible person was identified.	No safety precautions were taken regarding the use of materials. Only one of the group members is identified as the responsible person for the storage of materials.	All safety precautions were taken regarding the storage and use of the materials. However, only one member of the group was designated as responsible for this.	All safety precautions were taken regarding the storage and use of the materials. And all the group members were designated as responsible for this.
Evaluation of the Design				
Creating a Checklist and Using it for Evaluation Purposes	No checklist was created, and the design was not reviewed in any way.	No checklist was created, but the design was reviewed generally.	A checklist has been created but in no way was the design reviewed according to this list but in general.	A checklist was created with the participation of all group members and the design was reviewed according to the entire list.
Being realistic in terms of form and aesthetics	No emphasis was placed on form and aesthetics. Therefore, the design did not reflect reality.	The form of the design was determined. But since it is not based on aesthetics, the reality of the design was not reflective.	The design was all about form and aesthetics, but the design did not reflect reality.	The design was all about form and aesthetics, and the design did reflect reality almost completely.

What did you learn at this event?

What was your favorite part of this event?

Was there a section of this event that you didn't like?

What would you like to be changed in this event?

Figure 7. Reflecting Text.

Evaluation of the Activity

Throughout the activity, the work done by the groups was monitored by the teacher. The designs of the groups were analyzed through the Design Evaluation Rubric given in **Table 3**. While preparing this rubric, the rubric developed by Hacıoğlu et al. (2016) was utilized. The studies of the groups were analyzed through the Group Work Evaluation Rubric given in **Table 4**. While creating this rubric, the rubric developed by Aydın & Karaçam (2015) for evaluating technological designs for groups were utilized. Opinions about the activity were obtained from all students through reflection essays. These opinions are shown in **Figure 7**.

Discussion

"Let's Design a Water Slide Boat" is an activity design and implementation study demonstrating how to incorporate a STEM activity based on the engineering design process into science education. In this study, which deals with the 5th-grade science course Friction Force and Water Resistance, NASA's (2011) engineering design cycle has been taken as a basis. Therefore, in the activity, the steps of asking questions, imagining, planning, creating, testing, and improving follow each other cyclically. Using this cycle ensures that the activity topic designed in the study is associated with daily life. Because it was a STEM activity based on the EDP, the learners could work as engineers and scientists. For a quality science education, it is recommended that scientific research inquiry and engineering/technology design processes should be operated together in the learning process (NRC, 2012). In this way, both scientific research and engineering skills are developed. At the same time, the students understand the differences between science and engineering.

This study, a STEM activity, focused on essential achievements such as associating the science subject with daily life, creating ideas for solving the problem, designing, creating prototypes for the designs, testing, and evaluating the design. Based on design-based learning, this process enables individuals to produce original and creative solutions by approaching problems in a solution-oriented manner. It is reported in the literature that this design process increases students' motivation and encourages them to work collaboratively (Kroper et al., 2011). In support of this, it is stated that it is essential for individuals to have basic theoretical knowledge about the disciplines of Physics, Chemistry, Biology, and Mathematics (basic sciences) and the ability to create new products by combining this theoretical knowledge with knowledge in the fields of technology and engineering. STEM education is a crucial method (Pirrie, 2019). In STEM education, which focuses on production activities, individuals are expected to explore nature and the world innovatively, solve problems while exploring, and produce while solving problems (Affifi, 2019).

When successfully implemented and given the necessary importance to its pedagogical dimension, with this activity, it is possible to provide students with scientific process skills, 21st-century skills, and engineering skills or to develop their existing potential.

The literature supports this by reporting that children participating in STEM education develop scientific process skills (Strong, 2013). Engineering skills, especially innovative thinking, product creation, and the ability to approach problems from different perspectives come to the fore. The 21st-century skills supported in this activity are analytical thinking, decision-making, creative thinking, communication, teamwork, and entrepreneurship skills. The ultimate goal of these applications, which are a variation of design-based learning, is to increase learners' motivation and develop their higher-order thinking skills (Dopplet & Barak, 2021). In today's business world, individual skills such as problem-solving, analytical and creative thinking, and collaborative working are emphasized (World Economic Forum, 2017).

In this study, the fact that the activity was designed and implemented for 5th graders can be considered as a separate value because the literature emphasizes that STEM education should start at the youngest possible age (Chesloff, 2013). In addition, implementing such an activity in the classroom makes students active and ensures participation in the lesson. Similarly, it is stated that design-based STEM education enables children to participate in the process actively (Carroll et al., 2010).

As a result of this activity, the students learned the subject of water resistance and friction force in terms of content, and the knowledge they gained was permanent. This is supported by previous studies reporting that teaching this subject with STEM activities increases students' academic achievement (Changtong et al., 2020; Simeon et al., 2022). It is stated that STEM activities provide lifelong learning and also positively affect the skills of establishing relationships and problem-solving abilities (Wang, 2012). A Meta-Synthesis of studies on STEM education found that STEM education positively affected academic achievement in STEM disciplines and attitude toward school (Yıldırım, 2016). The same study also noted evidence that STEM education strengthens students' problem-solving and creativity.

In the engineering design phase of the activity, the development of learners' psychomotor skills was supported along with their design and creativity skills. In line with this idea, it is stated that using simple tools and materials such as scissors, glue, stickers, and cardboard during STEM activities will improve the skills of their students (Fortunati et al., 2014). Chang & Chen's (2022) research also states that robotics-based STEM activities significantly positively affect psychomotor performance.

This activity improved students' social skills. To substantiate this, the literature claims that STEM education programs help kids develop their social skills (Allen et al., 2019; Strawhacker & Bers, 2018). Collaborative work and communication skills come to the forefront in such activities (Cheng et al., 2013). It is also known that STEM activities provide opportunities for peer learning (Carroll et al., 2010).

This entrepreneurship-oriented STEM activity study aims to improve students' entrepreneurship skills. European Commission reports emphasize the importance and necessity of students' entrepreneurial skills (Council of the European Union, 2011). This situation is also reflected in the curriculum of science courses in Türkiye. In the curriculum, last updated in 2018, three basic skill steps were identified: life skills, scientific process skills, and engineering design skills. Life skills include entrepreneurship, communication, collaborative work, creative and analytical thinking, and decision-making skills. In order to help students acquire these skills, the program includes practices with the theme of "Science, engineering, and entrepreneurship." As a result, students are expected to integrate the scientific content knowledge in the Science course with engineering and entrepreneurship skills and create a product (MoNE, 2018). In this context, this activity, designed and implemented in our study, is an innovative activity to realize these goals of the Science course. In addition, this STEM activity contributes to students' cognitive, affective, and psychomotor skills.

This study, a STEM activity based on the engineering design process, may be used as a model for teaching various science subjects. Implementing STEM activities based on EDP at all educational levels is advised in light of the aforementioned potential outcomes.

References

Affifi, R. (2019). Between will and wildness in STEAM education. In Why Science and Art Creativities Matter. Leiden, The Netherlands: Brill.

Allen, P.J., Chang, R., Gorrall, B.K., Waggenspack, L., Fukuda, E., Little, T.D., & Noam, G.G. (2019). From quality to outcomes: A national study of afterschool STEM programming. *International Journal of STEM Education*, 6:37. DOI: https://doi.org/10.1186/s40594-019-0191-2

Aranda, M. L., Lie, R., & Selcen Guzey, S. (2020). Productive thinking in middle school science students' design conversations in a design-based engineering challenge. *International Journal of Technology and Design Education*, 30:67-81. DOI: https://doi.org/10.1007/s10798-019-09498-5

Ata Aktürk, A. (2023). "Teacher, I know how to do it": An engineering design-based STEM activity on the concepts of forces and floating/sinking for young problem solvers. *Science Activities*, 60(1):12-24. DOI: https://doi.org/10.1080/00368121.2022.2128709

Aydın, F., & Karaçam ,S.,(2015). A study of an analytic rubric for assessing technological design applications for groups. *Mersin University Journal of the Faculty of Education*, 11(1):132-147.

Baptista, M., & Martins, I. (2023). Effect of a STEM approach on students' cognitive structures about electrical circuits. *International Journal of STEM Education*, 10(1):1-21. DOI: https://doi.org/10.1186/s40594-022-00393-5

Baran E., Canbazoğlu Bilici S., & Mesutoğlu C. (2015). Science, technology, engineering, and mathematics (STEM) public service announcement (PSA) development activity. *Journal of Inquiry Based Activities*, 5(2):60-69.

Buber, A., & Unal Coban, G. (2020). From modeling to STEM: A predictor activity of volcanic eruption. *Science Activities*, 57(3):111-121. DOI: https://doi.org/10.1080/00368121.2020.1814193

Bybee, R. W. (2010). What is STEM education? *Science*, 329(5995):996.

Carroll, M., Goldman, S., Britos, L., Koh, J., Royalty, A., & Hornstein, M. (2010). Destination, imagination and the fires within: Design thinking in a middle school classroom. *International Journal of Art & Design Education*, 29(1):37-53. DOI: https://doi.org/10.1111/j.1476-8070.2010.01632.x

Chandrasekaran, S., Stojcevski, A., Littlefair, G., & Joordens, M. (2013). A comparative study of students' perceptions of project oriented design based learning in engineering education. Proceedings of the 24th Annual Conference of the Australasian Association for Engineering Education (AAEE 2013). Griffith School of Engineering, Griffith University.

Chang, C.C., & Chen, Y. (2022). Using mastery learning theory to develop task-centered hands-on STEM learning of Arduino-based educational robotics: Psychomotor performance and perception by a convergent parallel mixed method. *Interactive Learning Environments*, 30(9):1677-1692. DOI: https://doi.org/10.1080/10494820.2020.1741400

Changtong, N., Maneejak, N., & Yasri, P. (2020). Approaches for implementing STEM (Science, Technology, Engineering & Mathematics) activities among middle school students in Thailand. *International Journal of Educational Methodology*, 6(1):185-198. DOI: https://doi.org/10.12973/ijem.6.1.185

Cheng, C. C., Huang, P. L., & Huang, K. H. (2013). Cooperative learning in Lego Robotics Projects: Exploring the impacts of group formation on interaction and achievement. *Journal of Networks*, 8(7):1529-1535. DOI: https://doi.org/10.4304/jnw.8.7.1529-1535

Chesloff, J. D. (2013). STEM education must start in early childhood. *Education Week*, 32(23):27-32.

Christensen, R., & Knezek, G. (2017). Relationship of middle school student STEM interest to career intent. *Journal of Education in Science Environment and Health*, 3(1):1-13.

Council of the European Union, (2011). Conclusions on strengthening the external dimension of the EU Energy Policy. Brussels: European Council: 24 November.

Diana, N. (2021). Analysis of teachers' difficulties in implementing STEM approach in learning: A study literature. *Journal of Physics: Conference Series*, 1806(1):012219.

Doppelt, Y., & Barak, M. (2021). Design-based learning in electronics and mechatronics: Exploring the application in schools. In Design-Based Concept Learning in Science and Technology Education (pp. 101-134). Brill.

Doppelt, Y., Mehalik, M. M., Schunn, C. D., Silk, E., & Krysinski, D. (2008). Engagement and achievements: A case study of design-based learning in a science context. *Journal of Technology Education*, 19(2):22-39.

Eker, M. (2020). Investigation of the effects of STEM education applications on 5th grade students' science motivations and entrepreneurship. Master Thesis, Gazi University Institute of Educational Sciences, Ankara.

Fokides, E., & Papoutsi, A. (2020). Using Makey-Makey for teaching electricity to primary school students. A pilot study. *Education and Information Technologies*, 25(2):1193-1215. DOI: https://doi.org/10.1007/s10639-019-

10013-5
Fortunati, L., Esposito, A., Ferrin, G., & Viel, M. (2014). Approaching social robots through playfulness and doing-it-yourself: Children in action. *Cognitive Computation*, 6(4):789-801. DOI: https://doi.org/10.1007/s12559-014-9303-y
Hacıoğlu, Y. (2020). Implementation of thematic STEM education: Friction force example. *Boğaziçi University Journal of Education*, 37:3-21.
Hacıoğlu, Y., Yamak, H., & Kavak N. (2016). Teachers' views on engineering design-based science education. *Bartın University Journal of Faculty of Education*, 5(3):807-830.
Hynes, M., Portsmore, M., Dare, E., Milto, E., Rogers, C., Hammer, D., & Carberry, A. (2011). Infusing engineering design into high school STEM courses, pp.8-13. Available at: https://www.researchgate.net/publication/267233181_Infusing_Engineering_Design_into_High_School_STEM_Courses
İnce, K., Mısır, M. E., Küpeli, M. A., & Fırat, A. (2018). Examining the effect of stem-based approach on the problem solving ability and academic success of students in teaching the enigma of the earth's crust unit of the 5th grade life sciences course. *Journal of STEAM Education*, 1(1):64-78.
Kahveci, S. (2020). Analysis of science textbooks in terms of scientific process skills, levels of inquiry research based teaching method, stem approach and readability. Master Thesis, Trakya University Institute of Natural Sciences, Edirne.
Ke çeci, G., Alan, B., & Zengin, F. (2017). STEM education practices with 5th grade students. *Ahi Evran Üniversitesi Kırşehir Eğitim Fakültesi Dergisi*, 18:1-17.
Kroper, M., Fay, D., Lindberg, T., & Meinel, C. (2011). Interrelations between motivation, creativity and emotions in design thinking processes–an empirical study based on regulatory focus theory. In Design creativity 2010 (pp. 97-104). Springer, London.
Lou, S. J., Tsai, H. Y., Tseng, K. H., & Shih, R. C. (2014). Effects of implementing STEM-I project-based learning activities for female high school students. *International Journal of Distance Education Technologies (IJDET)*,12(1):52-73.
Mehalik, M. M., Doppelt, Y., & Schuun, C. D. (2008). Middle-school science through design- based learning versus scripted inquiry: Better overall science concept learning. *Journal of Engineering Education-Washington*, 97(1):71-85. DOI: https://doi.org/10.1002/j.2168-9830.2008.tb00955.x
Ministry of National Education (MONE) (2018). Science course curriculum. Ankara.
Moreno, N. P., Tharp, B. Z., Vogt, G., Newell, A. D., & Burnett, C. A. (2016). Preparing students for middle school through after-school STEM activities. *Journal of Science Education and Technology*, 25:889-897. DOI: https://doi.org/10.1007/s10956-016-9643-3
National Aeronautics and Space Administration [NASA] (2011). NASA System Engineering Design Process. https://ntrs.nasa.gov/api/citations/20110009921/downloads/20110009921.pdf
National Research Council [NRC]. (2012). A Framework for k-12 sciece education: Practices, crosscutting concepts, and core ideas. Washington DC: The National Academic Press.
National Research Council [NRC]. (2009). Engineering in K–12 education: Understanding the status and improving the prospects. Washington, DC: National Academies Press.
NGSS. (2013). Next Generation Science Standards: For states, by states. Washington, DC: The National Academies Press.
NGSS (2017). K-PS2 Motion and Stability: Forces and Interactions. http://www.nextgenscience.org/sites/default/files/dci-arrangement/K.PS2June2017.pdf
Özbilen, A. G. (2018). Teacher views and awareness on STEM education. *Scientific Educational Studies*, 2(1):1-21.
Pirrie, A. (2019). Where science ends, art begins?. In Why Science and Art Creativities Matter. Leiden, The Netherlands: Brill.
Simeon, M. I., Samsudin, M. A., & Yakob, N. (2022). Effect of design thinking approach on students' achievement in some selected physics concepts in the context of STEM learning. *International Journal of Technology and Design Education*, 32:185-212. DOI: https://doi.org/10.1007/s10798-020-09601-1
Stehle, S. M., & Peters-Burton, E. E. (2019).

Developing student 21st Century skills in selected exemplary inclusive STEM high schools. *International Journal of STEM Education*, 6(1):1-15. DOI: https://doi.org/10.1186/s40594-019-0192-1

Strawhacker, A.; Bers, M.U. (2018). Promoting positive technological development in a kindergarten makerspace: A qualitative case study. *European Journal of STEM Education*, 3:21.

Strong, M. G. (2013). Developing elementary math and science process skills through engineering design instruction. Master Thesis, Hofstra University School of Education, New York.

Tanık Önal, N., & Saylan Kırmızıgül, A. (2021). A Makey-Makey based STEM activity for children. *Science Activities*, 58(4):166-182. DOI: https://doi.org/10.1080/00368121.2021.2011086

Thomas, T. A. (2014). Elementary teachers' receptivity to integrated science, technology,engineering, and mathematics (STEM) education in the elementary grades Doctoral Thesis, University of Nevada, Reno.

Wang, H. (2012). A New era of science education: science teachers' perceptions and classroom practices of science, technology, engineering, and mathematics (STEM) integration. Doctoral Dissertation.

Wang, J., Werner-Avidon, M., Newton, L., Randol, S., Smith, B., & Walker, G. (2013). Ingenuity in action: Connecting tinkering to engineering design processes. *Journal of Pre-College Engineering Education Research (J-PEER),* 3(1):Article 2.

Wieselmann, J. R., Dare, E. A., Ring-Whalen, E. A., & Roehrig, G. H. (2020). "I just do what the boys tell me": Exploring small group student interactions in an integrated STEM unit. *Journal of Research in Science Teaching*, 57(1):112-144. DOI: https://doi.org/10.1002/tea.21587

World Economic Forum (2017). What are the 21st-century skills every student needs?. Available at: https://www.weforum.org/agenda/2016/03/21st-century-skills-future-jobs-students/

Yıldırım, B. (2016). An analyses and meta-synthesis of research on STEM Education. *Journal of Education and Practice*, 7(34):23-33.

Received: January 27, 2024
Revised: February 10, 2024
Accepted: June 2, 2024

Engineering Design-Based STEM Activity for Middle Schools: How Can I Slide Faster?

By Özlem Gökşen, Esra Kızılay, Nagihan Tanık Önal

Appendix 1.

WORKSHEET

NAME AND SURNAME,
GROUP MEMBERS

DESIGN TASK

How Can I Slide Faster?

Mert has been dreaming of a nice vacation all year and finally, summer vacation has arrived. Mert likes to spend most of his time at the water slides in the hotel pool and he is very excited to slide down the water slide. At his first slide, Mert doesn't enjoy it very much because he slides very slowly, and it hurts a little.

What do you suppose Mert's inability to move quickly down the slide could be?

If you were in Mert's shoes, what would you do to make it easier for him to slide?

Did anyone ever have a similar problem while sliding down the slide before? (If so, how did you solve the problem?)

Imagine a water slide boat design so that Mert can slide down the water slide more easily and draw the water slide boat you imagine in the space below (While imagining your designs; be careful that your designs are durable and safe and that their cost is low).

Calculate your expenses by writing the amount and price of the materials you will use in the table below.

Equipment/Material	**Price List**
Paper	1 TL for five
Scissors	5 TL each
Waste materials	Free of charge
Ruler	5 TL each
Pencil	1 TL for each
Glue	5 TL for a tube
Tape	5 TL for a roll
Needle	1 for 1 TL
Yarn	1 meter 1 TL
Cotton	8 TL for 50 g
Chenille	1TL each
Eva	1TL each
Wooden ice cream sticks	50 kr. each
Silicone gun	50 TL for one
Thin silicone	2 TL for 1

Materials Required	Pieces	Unit Price	Total

GRAND TOTAL:

Now make the boat which you have drawn.

Together with your group of friends, finish your water slide boat.

Imagine that you decide to sell your water slide boat that you have designed.

- What name will you use to sell your water slide boat?
- To whom will you sell your water slide boat?
- What would be the slogan of your advertisement to sell your water slide boat?
- What distinguishes your water slide boat from others?
- Why should people buy the water slide boat you have designed?

ORIGINAL ARTICLE

Development of a Protein Concept Inventory: A Proposal for Item Scoring and Responding

Güntay Taşçi

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Abstract: *The present study has aimed to develop and validate a protein concept inventory (PCI) consisting of 25 multiple-choice (MC) questions to assess students' understanding of protein, which is a fundamental concept across different biology disciplines. The development process of the PCI involved a literature review to identify protein-related content, validation interviews to iteratively validate and refine the created items (n = 26), and data collection from a large sample (n = 291) for statistical analysis. An expert interview was held with two different field experts regarding the content validity of the draft PCI tool, the suitability of the options, and the clarity of the items. Free choice format (multiple marking) was used to answer the developed MC items. In scoring these items, positive points were given to correct options, and negative points were given to incorrect options. Evidence regarding the psychometric properties of the PCI trial form was collected through factor analysis, group differentiation, internal consistency, and item analysis using quantitative data. The evidence collected demonstrates that the validity and reliability of the PCI as a measurement tool have been confirmed. PCI's scoring approach and the use of response patterns created by multiple markings in teaching are discussed.*

Science Insights Education Frontiers 2024; 23(2):3755-3777
DOI: 10.15354/sief.24.or617

How to Cite: Taşçi, G. (2024). Development of a protein concept inventory: A proposal for item scoring and responding. Science Insights Education Frontiers, 23(2):3755-3777.

Keywords: *Protein, Conceptual Understanding, Free Choice Format*

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***Conflict of Interests**: None*

***AI Declaration**: The author affirms that artificial intelligence did not contribute to the process of preparing the work.*

Introduction

CONCEPT inventories (CI) are widely used as a robust approach for evaluating conceptual understanding through the identification of misconceptions (D'Avanzo, 2008; Kalas et al., 2013; Klymkowsky & Garvin-Doxas, 2008; Libarkin, 2008). Starting with the Force Concept Inventory (Hestenes et al., 1992), CIs have been developed for various concepts (Newman et al., 2016). In relation to this, more studies have focused on developing CIs for teaching biology (Bybee, 2012; D'Avanzo, 2008; Garvin-Doxas et al., 2007). While these CIs may include a wide range of topics, including general biology, genetics, and microbiology, some concepts, such as homeostasis (McFarland et al., 2017) and natural selection (Anderson et al., 2002), have been selected. The widespread use of the CI approach has resulted in an essential body of literature on developing these tools. Researchers investigating the methods used for CI development have reported that these development processes include many variations (Lindell et al., 2007; Jorion et al., 2015). In this context, Adams and Wieman (2011) proposed a robust development framework with four fundamental phases for CI development. This framework included recommendations to identify the content and construction of the core concept, developing test specifications, field testing, validation interviews, scoring rules, and answering procedures.

Even though MC items are widely used in CIs due to their advantages, CIs are different from ordinary MC tests (Kalas et al., 2013; Smith & Knight, 2012). Stressed characteristics of CIs are measuring conceptual understanding, diagnosing understanding levels in learners (D'Avanzo, 2008; Garvin-Doxas et al., 2007; Libarkin, 2008), and containing research-based misconceptions in the options (distracters). This approach has been named distracter-driven MC items (Herrmann-Abell & DeBoer, 2011; Shin et al., 2019). Additionally, answering and scoring are other features of MC items discussed in the literature. Generally, the examinee can mark one of the options in an MC item, including the keyed item and other distracters. Its scoring is mainly determined by giving one (1) point for the correct answer and zero for the incorrect answer. This system is called "number right" (Kurz, 1999, p1). However, various other suggestions on scoring and responding to MC items are proposed in the literature (Frary, 1980; Frary, 1989; Hsu et al., 1984). According to Hsu et al. (1984), in the free-choice (multiple marking or multiple select) format instructions, the examinee can mark multiple options if they are correct. This method assumes that the examinee has preconceptions regarding the number of possible correct answers (Frary, 1989). Hsu et al. (1984) reported that in scoring items in the free-choice format, four points are given for the correct answer and minus points for each incorrect marking. According to Frary (1980), two different scoring methods exist for free-choice format items. The first was suggested by Coombs (1953), and the other was by Arnold and Arnold (1970). Thus, different response patterns score numerically. In studies on the development of biology concept inventories, MC items were mainly preferred, while multiple true-false items, open-ended questions, and stratified diagnostic items were less preferred (Queloz et al., 2017). In these studies, single-option marking has been generally used. The chance of the keyed answer, emphasized in the literature, is an essential limitation in this case. In their CI development study, Newman et al. (2016) used the multiple-select directive for MC items. Researchers reported that multiple-select effectively reduces random guessing.

Several studies directly related to protein structure, folding, chemical bonds, and amino acids in its structure have reported misconceptions in the field of biology (Fisher, 1985; Guzman & Bartlett, 2012; Kasapoglu, 2011; Harle & Towns, 2013; Linenberger & Bretz, 2014; Selvi & Yakışan, 2004; Robic, 2010; Villafañe et al., 2011). Robic (2010) summarized common misconceptions concerning protein structure with ten items. Harle and Towns (2013) indicated misconceptions of the formation of primary and secondary protein structures and the roles of chemical bond interactions by the students. Villafañe et al. (2011) have reported misconceptions about bond energy and protein alpha-helix structure. Misconceptions about protein synthesis, genes, DNA, chromosomes, mutation, and protein are also encountered in genetic and molecular genetics studies (Smith & Knight, 2012; Marbach-Ad, 2001; Gericke & Wahlberg, 2013; Smith & Williams, 2007; Guzman & Bartlett, 2012; Kasapoglu, 2011). Following this, White and Bolker (2008) outlined the close relationships between the genetic, biochemistry, and molecular genetic disciplines. Furthermore, several studies have reported protein-related misconceptions regarding diet, digestion, energy gain, and growth (Mak et al., 1999; Yilmaz et al., 2017).

Protein is crucial because it has a widespread teaching process from high school to higher education. It is also a critical core concept for fundamental biology disciplines like biochemistry and molecular genetics (White & Bolker, 2008). This literature shows that protein is an important core concept for different subject areas in biology. Accordingly, a conceptual understanding of the protein has been considered necessary. Therefore, the necessity of developing a PCI formed the basis of this study. The misconceptions were used as distracters, in line with other studies to measure this situation. In the study, the free choice format, which is in the measurement literature and rarely preferred in CI development studies, was chosen as the answering guide. Along with this response guide, unlike other studies, a scoring rule was used to create item scores, giving negative points for incorrect options and positive points for correct options. Thus, in the study, it was tried to determine qualitatively and quantitatively whether the response patterns obtained with multiple answers reflected the cognitive structure of the participants. In this context, the research's operational definition of conceptual understanding was accepted as the absence of misconceptions regarding the intended concepts in the cognitive structure of the learners. In the study, the response patterns were obtained with multiple responses. It was tried to determine whether the test reflects the cognitive structure and to examine the scores, validity, and reliability of these cognitive patterns.

Method

The study was conducted using the methodology reported in CI development studies in the literature. These studies include stages in which various qualitative and quantitative data collection stages are carried out. **Table 1** shows an overview of the CI's development process.

The study's qualitative data were obtained from a systematic literature review and validation interview with participants. Data analysis was provided with qualitative content analysis (Mayring, 2002) using MS Excel and MAXqda trial programs. SPSS, JASP, and MS Excel were used to analyze quantitative data for statistical evidence regarding validity and reliability.

Participants

The study included 317 participants. The validation interviews were conducted with 26 volunteers from the group. The participants were from different educational levels, including high school students (f = 10), university students (f = 13), biology teachers (f = 2), and one instructor.

The remaining 291 participants included 142 high school students (f = 120 females and f = 22 males), 96 university students (f = 80 females and f = 16 males), and 53 instructors. The high school level participants came from different high schools and attended various grade levels. Participants at the university level came from the departments of biology (f = 5), biology education (f = 14), science education (f = 50), and others (f = 27; health sciences, classroom teachers, and chemistry teachers). The teacher participants consisted of biology teachers (f = 31), science teachers (f = 13), and other branches (f = 3), a total of 47 teachers (17 males and 30 females). The average service period of these teachers was 14 years; however, working periods varied between 1 and 35 years. Six faculty members (three females and three males) worked at the university level. The teachers and faculty members were classified as the expert group in both applications of the study. However, this classification does not express any expertise in protein or biochemistry. It is solely based on the level of education gained.

Table 1. Overview of Applications in the Process of PCI Development and Criteria of Validity and Reliability.

Criteria	Applications	Content
Content Validity	1. Literature and fundamental resources reviewing	Identifying misconceptions and determining the conceptual framework for protein
Content validity	2. Forming of CI 2.1. Design of MC-questions 2.1.1. Item writing	
	2.1.2. The validation interviews (participants)	Understanding items by participants, defining misconceptions participants, and wording participants about items The accordance of response with argumentation
Construct validity	2.2. Draft PCI and test specification 2.2.1. Design response instruction and item-scoring rules	
	2.2.2. The validation interviews (experts)	The experts' opinions on the suitability content of PCI determined The accordance of item content with the aimed misconception
Construct validity	3. Statistical analysis 3.1. Validity 3.1.1. Factor analysis 3.1.2. Group comparisons	A large sampling application
	3.2. Reliability 3.3. Item analysis	

Literature and Fundamental Resources Reviewing

The first stage was a literature review to identify common misconceptions. To conduct a thorough literature analysis on misconceptions related to protein, various databases including "Google Scholar," "ERIC," and "SCOPUS" were searched using keywords such as "Protein," "Misconceptions in Biology," and "Misconceptions." Those related to protein and genetic concepts were selected first among the articles accessed. Then, articles that directly or also included protein-related misconceptions address protein-related misconceptions were selected. As a result of this, thirty-four articles from different countries were reached, and misconceptions about protein and protein-related concepts were reviewed. Simultaneously with this stage, essential sources (Nelson & Cox, 2016; Sadava et al., 2011; Simon et al., 2016) were examined. In this way, the conceptual framework of PCI and the list of misconceptions defined in various studies have been reached. Thanks to this list, multiple choice items began to be written to form the PCI.

Forming of Protein Concept Inventory

The researcher wrote items in a conventional MC format using the list of misconceptions area. The MC questions are about these misconceptions, and their options contain the misconceptions. The researcher initially wrote 28 MC questions. Then, validation interviews were conducted to examine these MC questions according to participants' thinking and wording. The participants' thoughts and explanations about protein were investigated with these items. To do this, participants solved the questions by thinking aloud about the questions and making explanations about their answers. The data of the participants from different education levels who participated in this process enabled testing the misconceptions determined with the support of the literature, revealing the students' understandings, and improving the items. These validity interviews with the participants were conducted interactively with question development in individual and group interviews. Based on this process, minor improvements were made to eight questions written at the beginning, significant improvements were made to 20 questions (total changing item roots or options), and seven new questions were written. As a result, 25 MC items were obtained through revisions carried out in three stages.

After creating the draft PCI, we conducted comprehensive interviews with two experts. First, the expert with a doctorate in biochemistry concluded that the items were related to the measured misconception, the keyed options were appropriate, and the conceptual framework for protein was sufficient. Then, the appropriateness of the form was reviewed by the researcher in terms of assessment and measurement according to the related literature (Haladyna & Downing, 1989; Haladyna & Steven, 1989; Nolen et al., 1992). Afterward, it was discussed with a field expert with a doctorate in educational sciences. The expert suggested some improvements for the items, such as making the expressions of item roots similar, avoiding two negative expressions, condensing lengthy option statements, having similar option lengths, and creating meaningful propositions with the question statement. The experts also expressed positive opinions about the test's presentation and response instructions. Twenty-five candidate items formed the PCI for a large sample application.

Design Response Instruction and Item-Scoring Rules

In scoring the participants' response patterns, scoring rules and their meanings were determined under the literature. The scorings of the response (cognitive) patterns are shown in **Table 2**.

Furthermore, these scores were compared with the number-right item scoring methods. Per the response instruction, each distracter (misconception) marked was given minus one (-1) point, and the correct option was given four (4) points; the sum of them formed the item scores. By scoring in this way, the highest score that can be obtained from an item is four (4) points,

Table 2. Comparison of Rules for Item Scoring and Levels of Understanding.

			Item Scores		
Levels of Understanding	Response combinations	Indices	Cognitive scores	pattern	Number-right scores
Scientific Conceptions (SC)	The only TO	I_1	4		1
Partial Understanding (PU)	A WO with TO	I_2	3		0
	Two WO with TO	I_3	2		0
	Three WO with TO	I_4	1		0
	All of the options	I_5	0		0
Lack of Knowledge (LK)	Do not know	I_0	0		0
	Do not know with TO or WO	I_{01}	0		0
Not Understanding (M)	Only a WO	M_1	-1		0
	Two WOs	M_2	-2		0
	Three WOs	M_3	-3		0
	Four WOs	M_4	-4		0

TO: true option; WO: wrong option

and it indicates scientific conception (SC) level (I1), namely, complete comprehension. Other positive scores (I_2–I_4) are called the level of partial understanding (PU). These scores suggest a cognitive structure in which the respondent has combined scientific conception with different misconceptions. Marking all options (I_5) is scored as zero (0) points in both scoring methods. This pattern is classified as PU because the respondents in test items are also given the option "I do not know." Furthermore, if the participant only marked the distracters, the item scores became a minus point (M_1–M_4), indicating a complete misconception or lack of understanding (M).

Statistical Analysis

Validity

Factor Analysis

The hypothesis on the structure of the items, which has been reached based on qualitative results, was tested using factor analysis. Exploratory factor analysis (EFA) was used to test the structure to be measured based on the relationship matrix between the participants' responses. The goodness of fit indices related to this structure was examined with confirmatory factor analysis (CFA). For this, the minimum residual (unweighted least square) method and Promax rotation, one of the oblique rotation techniques, were used for EFA. Both eigenvalue (> 1) and parallel analysis were performed to determine the number of dimensions. Finally, the PCI's construct was confirmed with CFA using JASP software (JASP Team, 2022). This stage was performed resampling using the bootstrap: 5000 and 95% confidence interval (95% CI) criteria.

Groups Comparisons

In high school education, students learn about proteins in various units throughout different educational periods. This means that their understanding of proteins is expected to increase over time. An analysis of variance (ANOVA) was conducted to test the statistical significance of the differences in PCI scores among high school participants from different educational periods. Owing to this analysis another piece of evidence for construct validity was provided based on the significance of the differentiation between groups in test scores.

Reliability and Item Analysis

For reliability, which is also related to validity, indices for internal consistency were calculated considering the construct validity findings. Firstly, Cronbach's alpha as an internal consistency criterion was calculated for reliability estimates compatible with the PCI factor structure. Additionally, item factor loads and error variance values produced by EFA and CFA were used in reliability estimation. Based on this, Guttman's lambda 6 and McDonald's Omega were calculated (Revelle & Zinbarg, 2009; Yurdugul, 2005). In addition, an item analysis was performed to evaluate the psychometric properties of the items. Item difficulty index, item discrimination (in the lower and upper 27% segments), and item-total correlation were calculated using understanding scores for item statistics. In these calculations, positive scores ranging from 0 to 8 were used by adding four to the cognitive pattern (understanding) scores (-4/4). The difficulty indices were calculated by the ratio of the item average to the maximum score that the item could get (Tan, 2016; p243). However, cognitive pattern scores (-4/4) were used in other statistical procedures.

Results

Results of Literature Review

Table 3. Descriptive Statistics of Articles in the Literature Review.

Sample of Studies	f	Methods	f	Type of article	f	Topics	f
Middle School	7	Experimental	3	Literature Review	2	Atom	1
Highschool	4	Document Analysis	5	Review	2	The plants	2
University	16	Mixed	3	Thesis	1	General biology concepts	5
Mixed	2	CI Development	2	Article	29	Circulation Systems	1
Biology Teacher In high school	1	Qualitative	5			Enzyme	5
		Survey	12			Digestive system	1
						Genetics and Genetics Concepts	10
						Protein structure and synthesis	8
						Cell Physiology	1

Previous studies on the misconceptions about protein or related concepts were selected to describe the misconceptions area regarding protein. **Table 3** presents the descriptive information about these articles.

In this way, 34 articles from different countries were reviewed in the literature analysis. The articles reviewed were published between the years 1985 and 2018. The samples of investigated research articles cover 6574 people from different education levels, and the book review studies include 19 national biology books from different countries. Especially review articles on misconceptions regarding the concept of protein (Robic, 2010) and general biology concepts (Vogel, 2000) were included. A part of the examined articles was on genetics and genetics concepts (f = 10), general biology concepts (f = 5), and enzymes (f = 5). In addition to this, articles directly related to protein structure and protein synthesis were found in eight studies. The cases of misconception reached by systematic literature analysis and their distribution according to subject areas are presented in **Table 4**.

Table 4 outlines the conceptual framework and misunderstandings related to proteins. These misunderstandings have been verified by analyzing various general biology and biochemistry resources. Based on these findings, the areas of study that form the conceptual framework of PCI, as well as the framework of misconceptions identified in the literature, have been obtained. This conceptual framework has been utilized to create test specifications for PCI questions. When the content of the test was formed, two main criteria were considered: protein topics and misconceptions. Accordingly, **Table 5** shows the distribution of the questions selected for PCI from the developed items according to topics and misconceptions about protein.

Table 4. The Subject Framework and Misconceptions about Protein.

Subject Domain	Misconceptions Area	Source
Amino acid	Misconceptions about the structure, synthesis, types of amino acids, and relationships among amino acids and genetic concepts	Vogel (2000); Fisher, (1985)
Protein structure	Misconceptions about the structural levels of the protein, its folding mechanism, the bonds in its structure, its formation in the cell, its 3-dimensional formations, denaturation, and its classification and specificity.	Villafañe et al., (2011); Vogel (2000); Smith & Knight (2012); Robic (2010); Lewis et al., (2000); Harle & Towns (2013)
Functions of the proteins	Misconceptions about the roles of protein, enzyme, and hormone concepts in vital events	Tekkaya et al.,(2000); Yip (1998a); Couch et al., (2015); Linenberger & Bretz (2014); Hershey (2004); Dikmenli et al., (2009)
Protein synthesis	Misconceptions about "The Central Dogma" information flow, Transcription, Translation, start and stop mechanisms, code, gene, codon, mRNA, anticodon, tRNA, and polysome.	Cho et al. (1985); Smith & Williams (2007); Guzman & Bartlett (2012); Kasapoglu (2011)
Genetic concepts and mutation	The misconceptions regarding gene, DNA, genotype to be protein, the role of the genetic codes in protein synthesis, and the effect of mutation.	Smith & Knight (2012); Cho et al. (1985); Gericke & Wahlberg (2013) Temelli (2006); Marbach-Ad (2001); Lewis et al., (2000)
Nutrient – Digestion – Cell - Metabolism	Misconceptions regarding the protein content of foods, the digestive mechanism, the state of their use in energy production, and that protein synthesis occurs only in eukaryotic cells.	Lewis et al. (2000); Yip, (1998b); Yilmaz et al.(2017); Mak et al. (1999) Wynn et al. (2017); Herrmann-Abell et al. (2016)

Results of Validation Interviews

With the validity-interviews analysis, 681 codes regarding different topics misconceptions. According to these findings, misconceptions about protein structure have the highest frequency (34.5%), followed by protein synthesis (21.29%) and genetic concepts (12.78%). Accordingly, it can be said that the misconceptions determined in the literature can be detected in the participants with the prepared items. Although the small number of participants in the validation interview and the absence of a quantitative sampling did not allow interpretations regarding the prevalence of the misconceptions, it indicates that the common misconceptions defined in the literature can be measured in these participants. However, it is critical to determine whether the options containing the misconceptions in the response patterns provided by the participants with multiple markings reflect their cognitive status. Thus, the consistency between the participants' response patterns and explanations has been investigated thanks to their marked options and explanations. **Table 6** presents some of these findings.

Table 6 shows the options containing the misconceptions selected by participants for the MC items. The explanations for these answers also include these misconceptions. Item 18 asked which of the following does not

Table 5. Distribution of Protein Concept Inventory Items by Topic and Subtopics.

Topics	Misconception Area	f	Item No
Genetic Concepts	Protein synthesis	1	3
	Protein diversity	1	12
	Mutation	1	17
	Genotype-phenotype protein relationship	1	18
	Protein-containing	1	23
Metabolism	Protein metabolism	1	6
Protein Functionality	Structure-function relationship	1	5
	Protein activity	1	11
	Specific binding	1	16
Protein Synthesis	Cell types	1	4
	Protein synthesis process	2	10-14
	Cell	1	15
Functions of the protein	Cellular functions	2	9 - 19
Structure of Protein	Amino acid	2	1 - 7
	Peptide bond	1	2
	Chemical bonds	1	8
	Types of protein	1	13
	Features of protein structure	1	20
	Formation of the original structure	1	21
	Distinctive feature	1	22
	Denaturation	1	24
	Structural levels	1	25

Table 6. Marked Options and Related Explanation.

Marked options (code of participants/question number)	The reason (code of participants/question number)
"Amino acids synthesize in the ribosome" (13/Question 2) "Amino acids are formed by the translation" (11/Question 2) "Amino acid is produced by tRNA. Amino acid synthesized in the ribosome" (5/Question 2)	"Ribosomes synthesize protein; therefore, they are the source of amino acids." (13/Question 2) "Amino acids are formed as a result of transcription. Encoded as reading (by translation)" (11/Question 2) "(Answer is) 2 (tRNA) and 3 (translation) because there is a production" (5/Question 2; 12). "Because the ribosome is a protein-specific organelle and synthesizes amino acids." (21/Question 2)
"Neuron, fungal cell, digestive tract, plant cell" (3/Question 18) "Neuron, digestive tract" (1/Question 18) "Neuron" (4/Question 18)	"Protein is produced in the ribosome. The ribosome is found in prokaryotes and eukaryotes in all living things. Bacteria produce protein. The neuron, fungal, plant cells, and digestive tract contain proteins, but these do not produce it." (3/Question 18) "For a protein-producing, it must have a ribosome organelle. It is absent in the neuron and digestive tract." (1/Question 18) "Neurons cannot reproduce, they cannot renew themselves (therefore) they cannot produce a protein (my answer) Neuron (nerve cell)" (4/Question 18)

realize protein synthesis. This question measures the misconception that some organisms or cell types cannot realize protein synthesis. According to their explanation in quotations, some participants (1, 3, and 4) believe that because neurons cannot divide or do not have ribosomes, they cannot produce protein. Similarly, the second question, which measures the misconceptions that amino acids are not synthesized in metabolic pathways in the cell, reveals the participants' misconception of the protein synthesis mechanism. These findings lead to the result that the response patterns formed by the developed questions are compatible with the cognitive structures of the participants.

Findings Regarding the Validity and Reliability

EFA Findings

The Kaiser–Meyer–Olkin value (0.939) in the EFA results is greater than 0.80, and Bartlett's test (Chi-square value = 2301.348. $p < 0.001$) is statistically significant. These findings show that the dataset is suitable for factor analysis in terms of sample size and correlation between items. Based on these findings, the scree plot was created for both a parallel analysis and eigenvalues.

Figure 1 shows that only one data point in the graph has an eigenvalue greater than the simulation data (triangle). The values indicate that the one-dimensional model developed by parallel analysis is acceptable. The variance explained by one dimension is 0.309, and the sum of the squares of the factor loads is 7.736. Based on this, the model has been accepted as one-dimensional.

Modification indices were obtained using CFA for the single-factor structure obtained by EFA. The goodness-of-fit criteria (X^2/df: 1.386; comparative fit index: 0.949; Tucker–Lewis Index: 0.944 root-mean-square error of approximation: 0.036; goodness-of-fit index: 0.907) were found to have a good level of fit in the CFA assessment of the one-dimensional structure obtained with the EFA result model (Hu & Bentler, 1999; Kline, 2005). **Table 7** shows the factor loads of the items calculated with CFA and EFA.

The CFA results (bootstrap 5000 and 95% CI) show that the predicted values for the items are significant within the confidence intervals. The factor loads calculated by CFA ranged from 0.346 to 0.655, and the EFA results were close. These results show that PCI has a one-dimensional factor structure.

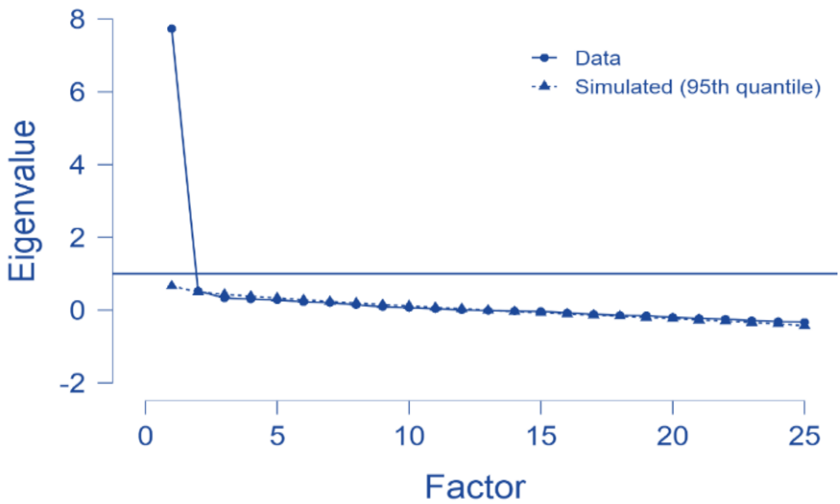

Figure 1. Scree Plot of the Eigenvalues and Parallel Analysis.

Table 7. Results for EFA and CFA.

	CFA						EFA	
				95% CI				
Items	Estimate	SE	z-value*	LL	UL	Std. Factor loads	Factor loads	Uniqueness
S1	1.000	0.000		1.000	1.000	0.404	0.403	0.838
S2	1.083	0.176	6.152	0.809	1.527	0.584	0.585	0.658
S3	1.331	0.222	6.004	0.981	1.915	0.552	0.554	0.693
S4	1.295	0.213	6.067	0.961	1.872	0.565	0.561	0.685
S5	1.144	0.202	5.667	0.815	1.680	0.488	0.489	0.761
S6	0.744	0.161	4.630	0.451	1.149	0.346	0.348	0.879
S7	1.281	0.205	6.236	0.933	1.875	0.604	0.603	0.637
S8	1.161	0.207	5.607	0.848	1.657	0.478	0.480	0.769
S9	1.339	0.223	6.013	0.967	1.955	0.554	0.553	0.694
S10	1.603	0.257	6.237	1.190	2.288	0.604	0.606	0.633
S11	1.119	0.201	5.561	0.793	1.619	0.471	0.473	0.776
S12	1.585	0.249	6.378	1.222	2.229	0.641	0.639	0.592
S13	1.371	0.230	5.960	1.017	1.965	0.543	0.543	0.705
S14	1.673	0.260	6.428	1.279	2.356	0.655	0.653	0.574
S15	1.286	0.210	6.133	0.942	1.851	0.580	0.578	0.666
S16	1.663	0.263	6.332	1.252	2.371	0.628	0.631	0.602
S17	1.477	0.230	6.409	1.115	2.084	0.649	0.649	0.579
S18	0.769	0.142	5.420	0.513	1.111	0.448	0.450	0.797
S19	1.195	0.202	5.925	0.860	1.718	0.536	0.537	0.711
S20	1.496	0.247	6.047	1.102	2.142	0.561	0.562	0.685
S21	1.597	0.259	6.170	1.192	2.268	0.588	0.586	0.656
S22	1.587	0.253	6.283	1.211	2.226	0.616	0.616	0.621
S23	1.409	0.225	6.276	1.047	2.006	0.614	0.613	0.624
S24	1.403	0.224	6.259	1.060	1.966	0.610	0.610	0.627
S25	0.960	0.177	5.408	0.633	1.454	0.447	0.445	0.802

*$p < 0.001$

Findings Related To Group Comparisons

Table 8 shows the ANOVA test results regarding the differences in the mean scores of the high school participants based on their grade levels.

Table 8 shows a significant difference in grade levels ($F(3; 138) = 8.083$, $p = 0.000$). Multiple comparison results show the source of this difference. The difference between the ninth grade and other grades—10th grade ($MD = -10.00$; $SE = 2.8$), 11th grade ($MD = -11.85$; $SE = 3.741$), and 12th grade ($MD = -17.51$; $SE = 3.405$)—is statistically significant at 95% CI. The mean score of ninth-grade classes ($M = 0.19$; $SD = 10.38$) is significantly lower than those of other grade levels. Although no significant difference was found between the averages of understanding scores of other grade levels (10−12), it is observed that the mean increases as the grade level increases.

Item Analysis and Reliability

The item statistics and reliability were calculated using the data's item scores. **Table 9** shows the results of the item analysis.

It can be seen that the item difficulty values range from 0.22 to 0.63. These values show that the PCI includes items with acceptable difficulty levels ($0.20 < p < 0.80$; Crocker & Algina, 1986, p98; Fisseni, 1997, as cited in Bühner, 2006, p140). When the correlational item discrimination indexes (r_{itc}) are examined, it is found that while they are low (< 0.30) for item six, they are medium to high (> 0.50) for the remaining items. The discrimination index (D, 27%) changed between 0.25 and 0.67. These findings indicate that the item discriminations are acceptable (> 0.20; Crocker & Algina, 1986, p315). With these data, the internal consistency criterion for reliability estimate was determined and is shown in **Table 10**.

When the table is evaluated, the reliability estimates calculated with different internal consistency measures of the developed PCI show that the test has a significant internal consistency and structural reliability.

Discussion

Validity and Reliability

The study was carried out the standards used in developing the CI and the criteria for measurement and evaluation by considering the relevant literature (Adams & Wieman, 2011; Crocker & Algina, 1986, pp217-218; Bühner, 2006, p36). Accordingly, concept domain determination comes first among the applications used for content validity (Crocker & Algina, 1986, pp217-

Table 8. One-Way ANOVA Results for the Grade Levels of High School Level Participants.

High School Grades	Mean	SD	n	F(3, 138)	η^2
9	0.19	10.38	31		
10	10.20	14.17	46		
11	12.05	14.86	21	8.083*	0.149
12	17.70	18.90	44		
Total	10.61	16.34	142		

p < 0.05.

Table 9. Item Analysis Results in Understanding Scores.

Items	Mean	Std. Dev.	Item Total correlations (r_{itc})	Index of Discrimination (D)	Item Difficulties (p)
S1	4.96	3.58	0.40	0.44	0.62
S2	3.27	2.70	0.60	0.42	0.41
S3	3.31	3.43	0.52	0.44	0.41
S4	4.46	3.29	0.53	0.53	0.56
S5	2.92	3.33	0.50	0.46	0.37
S6	4.55	3.04	0.22	0.25	0.57
S7	3.19	3.03	0.58	0.43	0.40
S8	5.01	3.49	0.47	0.49	0.63
S9	4.59	3.47	0.54	0.55	0.57
S10	2.74	3.77	0.59	0.54	0.34
S11	2.73	3.40	0.45	0.47	0.34
S12	3.92	3.54	0.60	0.55	0.49
S13	4.21	3.61	0.53	0.53	0.53
S14	4.09	3.67	0.65	0.67	0.51
S15	3.84	3.18	0.57	0.48	0.48
S16	2.98	3.77	0.61	0.57	0.37
S17	3.36	3.26	0.62	0.47	0.42
S18	3.34	2.48	0.44	0.29	0.42
S19	3.08	3.20	0.52	0.43	0.38
S20	3.44	3.80	0.54	0.54	0.43
S21	3.99	3.86	0.57	0.58	0.50
S22	3.70	3.68	0.58	0.65	0.46
S23	3.74	3.29	0.61	0.50	0.47
S24	3.32	3.27	0.58	0.48	0.41
S25	1.76	3.05	0.45	0.29	0.22

Note: n = 291; Test Mean: 90.485; Test Variance: 1885.954; Test Std. Dev: 43.428

Table 10. Frequentist Scale Reliability Statistics.

Estimate	McDonald's ω	Cronbach's α	Guttman's λ_6	Average Inter-item Correlation
Point estimate	0.916	0.914	0.921	0.298
95% CI lower bound	0.902	0.899	0.912	0.256
95% CI upper bound	0.930	0.927	0.940	0.341

218; Bühner, 2006, p36; Lindell et al., 2007). Adams and Wieman (2011), for example, described the structure and purpose of the field to measure as a standard. The content of the PCI was determined with systematic literature reviews. This content includes the subject, subtopic, and related misconceptions in a comprehensive framework from high school to higher education. Furthermore, qualitative interviews obtained the proposed expert opinions on content validity (Crocker & Algina, 1986).

The study provided evidence for construct validity in ways compatible with the literature (Adams & Wieman, 2011; Briggs et al., 2017; Kalas et al., 2013; Smith & Knight, 2012). These qualitative findings showed that item roots and options were first appropriately understood according to their wording participants, and second, the candidate items of the inventory revealed the participants' common misconceptions. The findings also showed that respondents' responses reflected their understanding and cognitive structure (**Table 6**).

In addition, the literature suggested that factor analysis techniques and differentiation between-group techniques effectively provided statistical evidence for construct validity (Crocker & Algina, 1986, p. 231; Kummer et al., 2019; Ramlo, 2008). Accordingly, the one-dimensionality of the EFA results was supported by the theoretical expectation and verified by CFA. The factor loads were within the desired values (> 0.30; **Table 7**) in the literature (Floyd & Widaman, 1995; Kline, 1994). Another proof of construct validity is the statistical significance of the difference among educational levels regarding PCI scores. While education levels include a wider interval for teaching the concept of protein, there are minor teaching differences between high school classes, including more similar age groups. Therefore, a significant difference in understanding of protein was expected in favor of the groups that received more education. The result provides evidence that the PCI discriminates between groups with and without more education about protein, consistent with theoretical expectations.

Internal consistency indices were calculated using different techniques for the reliability evidence of the developed PCI. Shevlin et al. (2000, as cited in Bühner, 2006, p134) recommend performing CFA to ensure one-dimensionality and calculating Cronbach's α accordingly. In addition to Cronbach's α coefficient, McDonald's ω and Guttman's λ6 coefficients were determined. These reliability coefficients are indices more sensitive to test structure, namely, dimensionality. In this context, McDonald's ω has been reported as an important index for structure reliability (Revelle & Zinbarg, 2009; Yurdugül, 2005). The high level of internal consistency coefficients (> 0.90) calculated in this way (**Table 10**) indicates that the developed inventory has a high internal consistency. According to the item analysis results (**Table 9**), the items were by the reference ranges requested in the measurement literature (Crocker & Algina, 1986; Bühner, 2006) and the CI development studies (Kalas et al., 2013; Paustian et al., 2017; Jarrett et al., 2012). The findings summarized are strong evidence for important psychometric properties of the PCI for measurement instruments.

Features of the PCI

The item score is the sum of the patterns for each option with a misconception score of minus one and a scientific conceptualization score of four points. In this way, PCI can produce scores for each item between −4 and 4 and for total of −100 and 100 points. In this study's scoring approach, whether or not there is a misconception in the response patterns is an important criterion. This criterion is commonly used in the literature for rubrics regarding understanding measurement (Naah, 2015). This situation supports our operational definition and PCI's scoring system (**Table 2**). The scoring properly matches the study's operational definition of conceptual understanding and allows us to evaluate in a broader range than classical scoring (0–1). When examining understanding scores, as these scores increase from negative to positive, comprehension improves, decreasing misconceptions in the cognitive structure. This condition leads to a more sensitive quantitative measurement and evaluation of participant differences. Furthermore, the PCI has provided a limited representation of cognitive structure thanks to the multiple markings. In this way, the participants' response patterns qualitatively show misconceptions. Thus, processing the data collected with the PCI using data analytics approaches (MS Excel, Power Pivot, or Dashboards) can quickly provide qualitative and quantitative information about the students' levels of understanding individually or at the class level to teachers.

Conclusions

Qualitative research findings and, in line with this, large sample research findings show that PCI measures protein-related misconceptions. In addition, the statistical analysis provided evidence regarding the validity and reliability of PCI. Accordingly, the PCI developed under the basic principles of the literature measures the level of understanding of the protein concept (Adams & Wieman, 2011; Briggs et al., 2017; Garvin-Doxas et al., 2007; Kalas et al., 2013; Libarkin, 2008). This study contributes to studies on CI development with the distracter-driven items presented in the literature and quantitative and qualitative analyses of cognitive pattern scores based on free-choice (multiple marking). Obtaining both quantitative and qualitative results with MC items, which are preferred due to their rapid, objective, and quantitative scoring features in the literature, contribute significantly to the evaluation of conceptual understanding both individually and as a group. PCI is an effective tool for researchers and teachers to measure understanding. PCI can help identify areas that require further teaching by analyzing the conceptual patterns that lead to misconceptions. Teachers can also use PCI to assess their students' prior knowledge and adjust their teaching accordingly. Additionally, PCI will be helpful for formative assessment purposes.

Ethics Statement

The participants were presented with an informed consent form before participating. The participants were informed that their participation in the test was entirely voluntary and that they could leave the study at any time. During the data collection, the data were anonymized, and no personal and corporate information was collected or used in the research. This study was conducted with the approval of Erzincan Binali Yıldırım University Human Research Ethics Committee (Protocol Number: 05/15).

Acknowledgment

I thank the field experts for their participation in the expert interviews and their valuable opinions, as well as all of the study's volunteer participants.

References

Adams, W. K., & Wieman, C. E. (2011). Development and Validation of Instruments to Measure Learning of Expert-Like Thinking. *International Journal of Science Education*, 33(9):1289-1312. DOI: https://doi.org/10.1080/09500693.2010.512369

Anderson, D. L., Fisher, K. M., & Norman, G. J. (2002). Development and evaluation of the conceptual inventory of natural selection. *Journal of Research in Science Teaching*, 39(10):952-978. DOI: https://doi.org/10.1002/tea.10053

Briggs, A. G., Hughes, L. E., Brennan, R. E., Buchner, J., Horak, R. E. A., Amburn, D. S. K., McDonald, A. H., Primm, T. P., Smith, A. C., Stevens, A. M., Yung, S. B., & Paustian, T. D. (2017). Concept Inventory Development Reveals Common Student Misconceptions about Microbiology. *Journal of Microbiology & Biology Education*, 18(3). DOI: https://doi.org/10.1128/jmbe.v18i3.1319

Bühner, M. (2006). Einführung in die Test- und Fragebogenkonstruktion (2nd ed.). Pearson Studium.

Bybee, R. W. (2012). The Next Generation of Science Standards : Implications for Biology Education. *The American Biology Teacher*, 74(8):542-549. DOI: https://doi.org/10.1525/abt.2012.74.8.3

Cho, H. H, Kahle, J. B., & Nordland, F. H. (1985). An investigation of high school biology textbooks as sources of misconceptions and difficulties in genetics and some suggestions for teaching genetics. *Science Education*, 69(5):707-719. DOI: https://doi.org/10.1002/sce.3730690512

Couch, B. A., Wood, W. B., & Knight, J. K. (2015). The Molecular Biology Capstone Assessment : A Concept Assessment for Upper-Division Molecular Biology Students. *CBE-Life Sciences Education*, 14:1-11. DOI: https://doi.org/10.1187/cbe.14-04-0071

Crocker, L., & Algina, J. (1986). Introduction to Classical and Modern Test Theory. Wadsworth Group- Thomson Learning.

D'Avanzo, C. (2008). Biology concept inventories: Overview, status, and next steps. *BioScience*, 58(11):1079-1085. DOI: https://doi.org/10.1641/b581111

Dikmenli, M., Çardak, O., & Öztaş, F. (2009). Conceptual problems in biology-related topics in primary science and technology textbooks in Turkey. *International Journal of Environmental and Science Education*, 4(4):429-440.

Fisher, K. M. (1985). A misconception in biology: Amino acids and translation. *Journal of Research in Science Teaching*, 22(1):53-62. DOI: https://doi.org/10.1002/tea.3660220105

Floyd, F. J., & Widaman, K. F. (1995). Factor analysis in the aevelopment and refinement of clinical assessment instruments. *Psychological Assessment*, 7(3):286-299. DOI: https://doi.org/10.1037/1040-3590.7.3.286

Frary, R. B. (1980). The effect of misinformation, partial information, and guessing on expected multiple-choice test item scores. *Applied Psychological Measurement*, 4(1):79-90. DOI: https://doi.org/10.1177/014662168000400109

Frary, R. B. (1989). Partial-Credit scoring methods for Multiple-Choice tests. *Applied Measurement in Education*, 2(1):79-96. DOI: https://doi.org/10.1207/s15324818ame0201

Garvin-Doxas, K., Klymkowsky, M., & Susan, E. (2007). Building, using, and maximizing the impact of concept inventories in the biological sciences: Report on a national science foundation-sponsored conference on the construction of concept inventories in the biological sciences. *CBE Life Sciences Education*, 6:297-306. DOI: https://doi.org/10.1187/cbe.07

Gericke, N., & Wahlberg, S. (2013). Clusters of concepts in molecular genetics: A study of Swedish upper secondary science students understanding. *Journal of Biological Education*, 47(2):73-83. DOI: https://doi.org/10.1080/00219266.2012.716785

Guzman, K., & Bartlett, J. (2012). Using simple manipulatives to improve student comprehension of a complex biological process: Protein synthesis. *Biochemistry and Molecular Biology Education*, 40(5):320-327. DOI: https://doi.org/10.1002/bmb.20638

Haladyna, T. M., & Downing, S. M. (1989). A taxonomy of multiple-choice item-writing rules. *Applied Measurement in Education*, 2(1):37-50. DOI: https://doi.org/10.1207/s15324818ame0201

Haladyna, T. M., & Steven, M. (1989). Validity of a taxonomy of multiple-choice item-writing rules. *Applied Measurement in Education*, 2(1):51-78. DOI: https://doi.org/10.1207/s15324818ame0201

Harle, M., & Towns, M. H. (2013). Students' understanding of primary and secondary protein structure: Drawing secondary protein structure reveals student understanding better than simple recognition of structures. *Biochemistry and Molecular Biology Education*, 41(6):369-376. DOI: https://doi.org/10.1002/bmb.20719

Herrmann-Abell, C. F., & DeBoer, G. E. (2011). Using distracter-driven standards-based multiple-choice assessments and Rasch modeling to investigate hierarchies of chemistry misconceptions and detect

structural problems with individual items. *Chemistry Education Research and Practice*, 12(2):184-192.DOI: https://doi.org/10.1039/c1rp90023d
Herrmann-Abell, C. F., Koppal, M., & Roseman, J. E. (2016). Toward high school biology: Helping middle school students understand chemical reactions and conservation of mass in nonliving and living systems. *Cell Biology Education*, 15(4).DOI: https://doi.org/10.1187/cbe.16-03-0112
Hershey, D. R. (2004). Avoid misconceptions when teaching about plants. Available at: http://Www.Actionbioscience.Org/Education/Hershey.Html?Print. & https://files.eric.ed.gov/fulltext/ED501356.pdf
Hestenes, D., Wells, M., & Swackhamer, G. (1992). Force concept inventory. *The Physics Teacher*, 30(3):141-158. DOI: https://doi.org/10.1119/1.2343497
Hsu, Tse-Chi, M., Moss, P. A., & Khampalikit, C. (1984). The merits of multiple-answer items as evaluated by using six scoring formulas. *The Journal of Experimental Education*, 52(3):152-158. Available at: http://www.jstor.org/stable/20151542
Hu, L., & Bentler, P. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling*. 6(1):1-55. DOI: http://www.tandfonline.com/doi/abs/10.1080/10705519909540118
Jarrett, L., Ferry, B., & Takacs, G. (2012). Development and validation of a concept inventory for introductory-level climate change science. *International Journal of Innovation in Science and Mathematics Education*, 20(2). Available at: https://openjournals.library.sydney.edu.au/CAL/article/view/5814
JASP Team (2022). JASP (Version 0.16.4) [Computer software].
Jorion, N., & Gane, B. D., & DiBello, L. V., & Pellegrino, J. W. (2015, June): Developing and Validating a Concept Inventory [Paper presentation]. *ASEE Annual Conference & Exposition*, Seattle, Washington. DOI: https://doi.org/10.18260/p.23836
Kalas, P., O'Neill, A., Pollock, C., & Birol, G. (2013). Development of a meiosis concept inventory. *CBE Life Sciences Education*, 12(4):655-664. DOI: https://doi.org/10.1187/cbe.12-10-0174
Kasapoglu, E. (2011). The effect of teaching protein synthesis using concept maps on the academic achievement and attitudes of 12th grade high school students. Master thesis. Sel çuk University.
Kline, P. (1994). An easy guide to factor analysis. Routledge.
Kline, R. B. (2005). Principles and practice of structural equation modeling (Second). The Guilford Press.
Klymkowsky, M. W., & Garvin-Doxas, K. (2008). Recognizing student misconceptions through Ed's tools and the biology concept inventory. *PLoS Biology*, 6(1):0014-0017. DOI: https://doi.org/10.1371/journal.pbio.0060003
Kummer, T. A., Whipple, C. J., Bybee, S. M., Adams, B. J., & Jensen, J. L. (2019). Development of an evolutionary tree concept inventory. *Journal of Microbiology & Biology Education*, 20(2). DOI: https://doi.org/10.1128/jmbe.v20i2.1700
Kurz, T. B. (1999). A review of scoring algorithms for multiple-choice tests. *Annual Meeting of the Southwest Educational Research Association* (San Antonio, TX, January 21-23, 1999, 1:1-21. Available at: https://files.eric.ed.gov/fulltext/ED428076.pdf
Lewis, J., Leach, J., & Wood-Robinson, C. (2000). All in the genes? Young people's understanding of the nature of genes. *Journal of Biological Education*, 34(2):74-79. DOI: https://doi.org/10.1080/00219266.2000.9655689
Libarkin, J. (2008). Concept inventories in higher education science. STEM Education Workshop 2. Available at: https://sites.nationalacademies.org/cs/groups/dbassesite/documents/webpage/dbasse_072624.pdf
Lindell, R. S., Peak, E., & Foster, T. M. (2007). Are they all created equal? A comparison of different concept inventory development methodologies. *AIP Conference Proceedings*, 883:14-17. https://doi.org/10.1063/1.2508680
Linenberger, K. J., & Bretz, S. L. (2014). Biochemistry students' ideas about shape and charge in enzyme-substrate interactions. *Biochemistry and Molecular Biology Education*, 42(3):203-212. DOI: https://doi.org/10.1002/bmb.20776
Mak, S. Y., Yip, D. Y., & Chung, C. M. (1999). Alternative conceptions in biology-related topics of integrated science teachers and implications for teacher education. *Journal of Science Education and Technology*,

8(2):161-170. DOI: http://www.jstor.org/stable/40188526
Marbach-Ad, G. (2001). Attempting to break the code in student comprehension of genetic concepts. *Journal of Biological Education*, 35(4):183-189. DOI: https://doi.org/10.1080/00219266.2001.9655775
Mayring, P. (2002). Einführung in die qualitative sozialforschung (5. edition). Beltz Verlag.
McFarland, J. L., Price, R. M., Wenderoth, M. P., Martinková, P., Cliff, W., Michael, J., Modell, H., & Wright, A. (2017). Development and validation of the homeostasis concept inventory. *CBE Life Sciences Education*, 16(2):1-13. DOI: https://doi.org/10.1187/cbe.16-10-0305
Naah, B. (2015). Enhancing preservice teachers' understanding of students' misconceptions in learning chemistry. *Journal of College Science Teaching*, 45(2):41-47. DOI: https://doi.org/10.2505/4/jcst15_045_02_41
Nelson, D. L., & Cox, M. M. (2016). Lehninger Principles of Biochemistry(Y. M. Elçin (ed.); 5th ed.). Palme Publshing.
Newman, D. L., Snyder, C. W., Fisk, J. N., & Wright, L. K. (2016). Development of the central dogma concept inventory (CDCI) assessment tool. *CBE Life Sciences Education*, 15(2). DOI: https://doi.org/10.1187/cbe.15-06-0124
Nolen, S. B., Haladyna, T. M., & Haas, N. S. (1992). Uses and abuses of achievement test scores. *Educational Measurement: Issues and Practice*, 1992:9-15. DOI: https://doi.org/10.1111/j.1745-3992.1992.tb00234.x
Paustian, T. D., Briggs, A. G., Brennan, R. E., Boury, N., Buchner, J., Harris, S., Horak, R. E. A., Hughes, L. E., Katz-Amburn, D. S., Massimelli, M. J., McDonald, A. H., Primm, T. P., Smith, A. C., Stevens, A. M., & Yung, S. B. (2017). Development, validation, and application of the microbiology concept inventory. *Journal of Microbiology & Biology Education*, 18(3). DOI: https://doi.org/10.1128/jmbe.v18i3.1320
Queloz, A. C., Klymkowsky, M. W., Stern, E., Hafen, E., & Köhler, K. (2017). Diagnostic of students' misconceptions using the Biological Concepts Instrument (BCI): A method for conducting an educational needs assessment. *PLoS ONE*, 12(5):1-18. DOI: https://doi.org/10.1371/journal.pone.0176906
Ramlo, S. (2002). The Force and Motion Conceptual Evaluation. *Annual Meeting of the Mid-Western Educational Research Association*. Available at: https://files.eric.ed.gov/fulltext/ED471542.pdf
Ramlo, S. (2008). Validity and reliability of the force and motion conceptual evaluation. *American Journal of Physics*, 76(9):882-886. DOI: https://doi.org/10.1119/1.2952440
Revelle, W., & Zinbarg, R. E. (2009). Coefficients alpha, beta, omega, and the glb: Comments on sijtsma. *Psychometrika*, 74(1):145-154. DOI: https://doi.org/10.1007/s11336-008-9102-z
Robic, S. (2010). Mathematics, thermodynamics, and modeling to address ten common misconceptions about protein structure, folding, and stability. *Cell Biology Education*, 9:323-332. DOI: https://doi.org/10.1187/cbe.10
Sadava, D., Hillis, D. M., Heller, H. C., & Berenbaum, M. R. (2011). Life: The Science of Biology (E. Gündüz & İ. Türkan (eds.); 9th ed.). Palme Publishing.
Selvi, M., & Yakışan, M. (2004). Misconceptions about enzymes in university students. *Gazi Eğitim Fakültesi Dergisi*, 24(2):173-182. DOI: https://doi.org/10.17152/GEFD.02048
Shin, J., Guo, Q., & Gierl, M. J. (2019). Multiple-choice item distracter development using topic modeling approaches. *Frontiers in Psychology*, 10:1-14. DOI: https://doi.org/10.3389/fpsyg.2019.00825
Simon, E., Dickey, J., Reece, J., & Hogan, K. (2016). Campbell Essential Biology With Physiology (E. Gündüz & İ. Türkan (eds.); 5th ed.). Palme Publishing.
Smith, L. A., & Williams, J. M. (2007). "It's the X and Y thing": Cross-sectional and longitudinal changes in children's understanding of genes. *Research in Science Education*, 37(4):407-422. DOI: https://doi.org/10.1007/s11165-006-9033-6
Smith, M. K., & Knight, J. K. (2012). Using the genetics concept assessment to document persistent conceptual difficulties in undergraduate genetics courses. *Genetics*, 191(1):21-32. DOI: https://doi.org/10.1534/genetics.111.137810
Tan, Ş. (2016). Measurement and Evaluation in

Teaching (12th ed.). Pegem Akademi.
Tekkaya, C., Çapa, Y., & Yılmaz, Ö. (2000). Biology teacher candidates' misconceptions about biology. *HU Journal of Faculty of Education*, 18:140-147. Available at: https://dergipark.org.tr/tr/pub/hunefd/issue/7818/102721#article_cite
Temelli, A. (2006). Determination of misconceptions concerning genetic subjects of high school students'. *Kastamonu Education Journal*, 14(1):73-82. Available at: https://dergipark.org.tr/tr/download/article-file/819169
Villafañe, S. M., Loertscher, J., Minderhout, V., & Lewis, J. E. (2011). Uncovering students' incorrect ideas about foundational concepts for biochemistry. *Chemistry Education Research and Practice*, 12(2):1-6. DOI: https://doi.org/10.1038/nn.2744
Vogel, S. (2000). Mythology in introductory biology. Resonance, 2000:86-95.
White, B. T., & Bolker, E. D. (2008). Interactive computer simulations of genetics, biochemistry, and molecular biology. *Biochemistry and Molecular Biology Education*, 36(1):77-84. DOI: https://doi.org/10.1002/bmb.20152
Wynn, A. N., Pan, I. L., Rueschhoff, E. E., Herman, M. A. B., & Archer, E. K. (2017). Student Misconceptions about Plants - A First Step in Building a Teaching Resource. *Journal of Microbiology & Biology Education*, 18(1):0-13. DOI: https://doi.org/10.1128/jmbe.v18i1.1253
Yilmaz, M., Ertunç G., Hatun Diken, E., & Çimen, O. (2017). The analysis of biology topics in the 8th grade science textbook in terms of scientific content. *Erzincan University Journal Faculty of Education*, 19(3):17-35. DOI: https://doi.org/10.17556/erziefd.330600
Yip, D. Y. (1998a). Identification of misconceptions in novice biology teachers and remedial strategies for improving biology learning. *International Journal of Science Education*, 20(4):461-477. DOI: https://doi.org/10.1080/0950069980200406
Yip, D. Y. (1998b). Teachers' misconceptions of the circulatory system. *Journal of Biological Education*, 32(3):207-215. DOI: https://doi.org/10.1080/00219266.1998.9655622
Yurdugul, H. (2005). The comparison of reliability coefficients in parallel, tau-equivalent, and congeneric measurements. *Ankara University Journal of Faculty of Educational Sciences*, 39(1):15-37. DOI: https://doi.org/10.1501/egifak_0000000127

Received: February 25, 2024
Revised: March 4, 2024
Accepted: March 25, 2024

ORIGINAL ARTICLE

Biology Teacher Candidates Drawings about Circulatory System

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Abstract: *The purpose of the drawing method is to reveal the hidden beliefs, attitudes, knowledge and understanding of students without being dependent on words. It is more useful than other techniques in that it is easy to apply and a lot of data can be obtained with a drawing. Some misconceptions can be revealed by asking students to describe or illustrate some objects or phenomena. Biology is mostly concerned with the diagnosis of structures, their interrelationships and their functions. For this reason, it is very important to draw the biological structures correctly. Human circulatory system' comprehension is a major point in biology education. Because understanding this system is a basis for learning the transport and exchange of substances in the human body, the lymphatic system, gas exchange, and other important biological concepts. The aim of this study is to examine the cognitive structures of biology teacher candidates about the "circulatory system" with the drawing technique. In this study, a case study was conducted to reveal the biology teacher candidates' drawings in detail. In order to explore biology teacher candidates' drawing of the circulatory system in detail, their drawings were collected as data through 32 high school students (teacher candidates) in biology education faculty from Turkey. After the drawings were completed, each drawing was effectively scored for the presence or absence of at least one organ/structure in circulatory system. In addition, the drawings were further reclassified, taking into account the pattern of the path of pulmonary and systemic circulations. According to the findings obtained from the drawings of the biology teacher candidates about the circulatory system, it was revealed that the teacher candidates had many misconceptions, mistakes and incomplete information.*

Science Insights Education Frontiers 2024; 23(2):3779-3797
DOI: 10.15354/sief.24.or621

How to Cite: Özay Köse., E. (2024). Biology teacher candidates drawings about circulatory system. Science Insights Education Frontiers, 23(2):3779-3797.

***Keywords**: Circulatory System, Biology Teacher Candidates, Drawings*

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***Conflict of Interests**: None*

***AI Declaration**: The authors affirm that artificial intelligence did not contribute to the process of preparing the work.*

Introduction

THERE HAS BEEN a long-standing disagreement about the extent to students' understanding that conflicts with what is accepted scientifically, named as misconceptions, naive beliefs, alternative concepts and so forth (Behrendt et al., 2001; Matthews, 1998; Reiss & Tunnicliffe, 2021). Yip (1998) explains misconceptions as thoughts and ideas put forward by students that are inconsistent with scientific knowledge. Misconception can also be defined as students' thinking about a subject differently from the experts on that subject (Driver & Easley, 1978). It is possible to define misconception as the way in which a person understands a concept is used significantly different from its commonly accepted scientific meaning (Marioni, 1989; Riche, 2000; Stepans, 1996).

Misconceptions can be observed in many subject areas (Science, Physics, Chemistry, Biology, Mathematics, Geography) and at age level (preschool, primary education, secondary education, university and later). The claim that misconceptions can be found in all subjects involving people's mental activities seems appropriate or corrects (Baysen et al., 2012). As a result of research conducted in recent years, it has been determined that students in the field of biology, as in other science fields, encounter difficulties in learning many biology subjects and develop misconceptions about these biology subjects. The nature and complexity of biological concepts and the abstract or hidden aspects of natural phenomena make biology a particularly difficult field to teach and learn (Bennett, 2003; Brown & Schwartz, 2009; Rotbain et al., 2008). Students' misconceptions may be caused by their experiences, the language they use in daily communication, the content knowledge of their teachers and textbooks (King, 2009). Students form concepts at an early age as they explore their physical and social worlds. That is, children's misconceptions about natural events usually develop before they start school (Driver, 1988).

One of the most important goals of science education is to enable students to learn and apply science concepts correctly. For this reason, before teaching science subjects, it is necessary to reveal the concepts that students have about the subject. Because students' prior knowledge must be research to remove that students have misconceptions about many science concepts (Yağbasan & Gülçiçek, 2003). These misconceptions are valuable and indispensable for students as they are developed by their individual experiences. Therefore, students are reluctant to correct their misconceptions. In order to make science teaching effective with the developed strategies, first of all, students' misconceptions about science concepts should be identified and eliminated. As a result of this, many researchers have focused on the diagnosis and treatment of misconceptions that students have (Kumandaş et al., 2019; Riche, 2000).

Results from other studies reveal how the strategies listed can help students uncover their misconceptions: concept mapping (Novak & Gowin, 1984), stories and explanations that challenge misconceptions (Novak & Musonda, 1991), predict-observe-explain activities (Liew & Treagust, 1995), and drawing activities (Dempsey & Betz, 2001; Gul & Ozay Kose, 2021; Patrick and Tunnicliffe, 2010; Reis et al., 2002).

The purpose of the drawing method is to reveal the hidden beliefs, attitudes, knowledge and understanding of students without being dependent on words (Pridmore & Bendelow, 1995). Drawings are useful in determining the student's mind and level of understanding for his/her answer. It is more useful than other techniques in that it is easy to apply and a lot of data can be obtained with a drawing. Some misconceptions can be revealed by asking students to illustrate some objects or phenomena.

An important part of biological studies is to capture the architectural structures of living things. The drawing process is a pictorial record of observation and interpretation. Use the drawing helps to describe the complex relationships of biological structures. Biology deals with the determination of structures, functions and relations with each other. For this reason, it is important to be able to draw biological structures. Biology is mostly concerned with the diagnosis of structures, their interrelationships and their functions. For this reason, it is very important to draw the biological structures correctly. The correct presentation of the biological structures in the drawings is achieved by the correct naming of the structures. The correct relations between the structures and their functions are provided with short explanations written next to the figures.

Drawing is an educational/teaching activity frequently done by students of all levels in schools. Biologists consider the drawing activity useful and use it frequently in the laboratory, anatomical and microscopic studies, and in the field (Dempsey & Betz, 2001). Biology concepts are not represented in print by words alone. They are also visually represented as different diagrams (Cheng & Gilbert, 2014). In the biology lesson, drawing is mostly used to record the things observed and to reveal student understanding of the subject such as organism's cells, tissues, organs and organism specimens. In addition, drawing is an important tool for many educational researchers to help students understand basic biological concepts. However, students can show a wide variety of ideas with drawings. In other words, drawings are different from classical written texts, which students remember what they have learned and understood in the classroom without explanation (Nugraha, 2016).

It is important to learn the human circulatory system in biology. It is important not only because it is a basic human physiological system, but also because it plays a key role in learning the transport and exchange of substances in the human body, gas exchange, lymphatic system and other important biological concepts. In addition, understanding cardiovascular disease and its treatment is related to knowing the concepts related to the circulatory system well (Cheng & Gilbert, 2015).

The understanding of the circulatory system seems to pose a major conceptual difficulty (López-Manjón & Angón, 2009). Learning the human circulatory system is quite difficult. Because at the system level, students should know the main functions of the whole system, namely the transport and exchange of blood. At the organ level, students have to relate the structures and functions of individual organs. Meanwhile, they also need to know how the different functions and structures of individual organs/tissues are arranged to serve system functions (Cheng & Gilbert, 2015).

A number of studies were carried out in which young people were asked to draw on the organ systems of what was inside them:

Conceptual understanding through drawing was investigated in a study conducted with 116 pre-service teachers at a university in Turkey. As a result of the research, it was revealed that 50.9% of the pre-service teachers partially depicted the human digestive system (partial understanding) and only 19.8% understood it fully (Çardak & Dikmenli, 2018). In another study, it was revealed that students had deficiencies in understanding organ systems and most of the students had knowledge about the organ but could not establish a detailed relationship between organ systems, for example, students knew bones but could not draw skeletal systems (Reiss & Tunnicliffe, 2001). In another study, information about the location, shape and function of human internal organs was investigated and it was revealed that more than 50% of the students had problems in drawing the shape of human internal organs and determining their correct location (Prokop & Fančovičová, 2006). In another study, it was revealed that eighth grade students had extensive knowledge about internal organs, but had a poor understanding of how organs work (Özsevgeç, 2007).

Arnaudin and Mintzes (1985, 1986) analyzed issues related to the circulatory system, such as the structure and function of the blood and heart, the circulatory system, the relationships between the circulatory and respiratory systems, and the nature of the closed circulatory system. To determine the type of circulatory pathway, they asked students to choose from a variety of drawings showing the pathways of a drop of blood from the heart to the toe. According to the results obtained, it was observed that the students had difficulties in understanding the blood circulation path. In a study investigating conceptual understanding through circulatory system, students were asked to draw and explain the circulation path of blood on the human body. According to the results obtained, it was seen that 29% of the students did not have a scientific model of the circulatory system following the instruction (Chi, 2005). Reiss, Tunnicliffe et al. (2002), asked students of different ages to draw what is inside their own bodies. According to the analyzes, it was determined that the students showed very little the related structures of the organs within the organ systems and most of them still had very little understanding of the organ systems. Patrick and Tunnicliffe (2010), in their study in which science teachers revealed their understanding of the internal structures of the human body; they found that teachers could draw organs one by one, but they could not draw the relationship between organs and organ systems.

Learning the circulatory system also requires understanding the various diagrams involved, as well as reading and understanding the relevant text. It has been reported that some students only use their verbal memory while learning some scientific concepts. While their verbal recall was scientifically correct, when asked to transcribe their verbal descriptions, their drawings were unscientific translations of verbal recall. That is, students memorized scientifically acceptable verbal information. Since learning many biological processes and functions requires the correct spatiality of structures, it will be useful to have students draw the structure and function of biological components (Cheng & Gilbert, 2015).

Existing research has reported pre-service biology teachers' concepts of human binary circulation. This study explored pre-service biology teachers' knowledge of circulatory system structures and organs and how they could visualize the blood flow between them and some of their drawings that show the blood flow path through the circulatory system. The aim of this study is to examine the cognitive structures of biology teacher candidates about the "circulatory system" with the drawing technique. For this purpose, biology teacher candidates were asked to make the following drawings.

1. Draw the structures and organs of the circulatory system and write their parts on the drawing. It doesn't matter if the drawing is artistic. If you wish, you can write the details of the organs and structures you have drawn next to them.
2. Draw the blood flow in the pulmonary and systemic circulations in the circulatory system. Write their parts on the drawing. It doesn't matter if the drawing is artistic. If you want, you can write down the steps of the path you have drawn.

Method

In order to reveal a more detailed understanding of biology teacher candidates' drawings, a case study was used in this study.

Participants

In order to reveal a more detailed understanding of biology teacher candidates' drawing of the circulatory system, their drawings were collected as data through 32 biology teacher candidates in education faculty from Turkey. Their ages were between 20 and 21. They were taught the topic human circulatory system during the previous year.

Procedure

In order to draw the circulatory systems, pre-service biology teachers were given 20 minutes to complete their drawings. Before of drawing session, it was expressed that "*You won't get any points from this work, so please don't copy each other's drawings. We are only interested in your knowledge of the human circulatory system. Also, it doesn't matter if the drawing is artistic*". After the drawings were completed, each drawing was effectively scored for the presence or absence of at least one organ/structure in circulatory system. In addition, the drawings were classified, taking into account the pattern of the path of pulmonary and systemic circulations.

Analysis Criteria

Each drawing was effectively scored for the presence or absence of at least one organ/structure in circulatory system. Each drawing was scored independently by two biology teacher. The structures in the drawings have been digitized and given as a list. Each organ/structure in the list is presented in **Table 1**. In addition, the codes and categories of each structure were created by examining the drawings one by one, and the findings were presented with numerical values. In the display of numerical values, the number of biology teacher candidates (f) and the biology teacher candidates' ratio (%) indicating the organ/structure/section in the research are given in separate columns in the table (**Table 2**).

In addition, the drawings were classified, taking into account the path of pulmonary and systemic circulations. Drawings were classified using the same stages Biology of Campbell et al. (2016) (**Figure 1**). In this figure, there are 11 stages that 4 of them are pulmonary circulate stages and 7 of them are systemic circulate stages. Biology teacher candidates received points for each stage drawn (**Table 3**).

Pulmonary Circulate

1. It begins with contraction of the right ventricle of the heart.
2. The blood is pumped into the pulmonary arteries, which are the arteries that bring oxygen-poor blood to the left and right lungs.
3. This oxygen-poor blood then enters into a dense network of capillaries that blankets the entire respiratory surface of the lung. It is

Table 1. Descriptive Statistics of Biology Teacher Candidates' Drawings.

Organ/Structure	f	%
Heart	30	94
Lungs	14	44
Arteries	26	81
Venules	26	81
Capillaries	8	25
Blood	12	38

Table 2. Findings of Drawings for The Circulatory System.

Structure	Section	f	%
Heart	Atriums	24	75
	Ventricules	24	75
	Semilunar Valve	8	25
	Atrioventricular Valve	8	25
	Heart walls	4	13
	S.A. Node	2	6
	A.V Node	2	6
	Purkinje Fibers	2	6
	Bundle Branches	2	6
Lungs	Bronchus	8	25
	Bronchiole	8	25
	Alveoli	4	13
Blood	O2-Rich Blood	18	56
	CO2- Rich Blood	18	56
	Leukocytes	2	6
	Erithrocytes	2	6
Venules	Pulmonary Vein	24	75
	Superior Vena Cava	12	38
	Inferior Vena Cava	10	31
Arteries	Aorta	28	88
	Pulmonary Artery	20	63
Capillaries	Endothelium	4	13

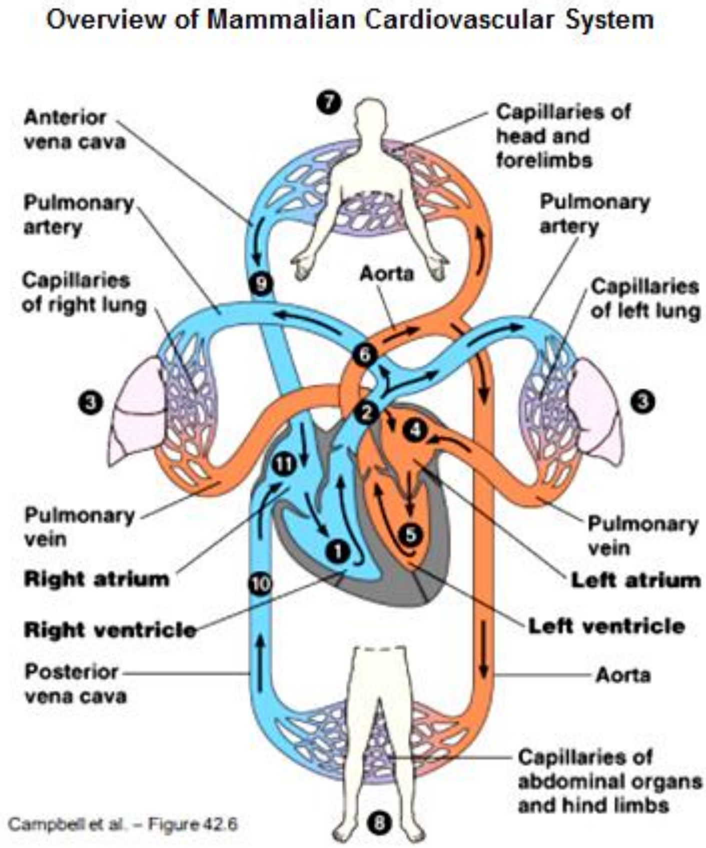

Figure 1. The Pulmonary and Systemic Circulations in the Circulatory System.

Table 3. Percentage of Biology Teacher Candidates' Drawing for Blood Circulation.

Stages	f	%
1	20	62
2	24	75
3	0	0
4	24	75
5	20	62
6	24	75
7	6	18
8	20	62
9	6	18
10	20	62
11	20	62

here where the blood releases carbon dioxide into the lungs and absorbs oxygen.

4. The oxygen-rich blood enters the pulmonary veins, which are the veins that bring oxygenated blood from the lungs back to the heart.

Systemic Circulate

1. From the pulmonary veins, blood enters the left side of the heart and is pumped into the aorta, which is the main artery that leads directly out of the left side of the heart.
2. The aorta is the largest blood vessel in the human body, and branches off into many smaller arteries that bring oxygenated blood to the various tissues of the body.
3. The blood then enters capillaries that distribute the blood to every cell in upper parts of the body, oxygen is released into the tissues and carbon dioxide is picked up by the blood.
4. The blood then enters capillaries that distribute the blood to every cell in lower parts of the body, oxygen is released into the tissues and carbon dioxide is picked up by the blood of the body
5. The blood is then collected back into veins (superior vena cava),
6. The blood is then collected back into veins (inferior vena cava),
7. Oxygen-poor blood returns to the right atrium of the heart and the cycle is ready to repeat itself (Campbell et al., 2016).

Findings and Discussion

In the process of analyzing the data obtained from the biology teacher candidates drawings in the research, the extent to which the organs/structures that make up the circulatory system are included for the first research problem were examined in detail. Each organ/structure is presented in Table 1. In the display of numerical values, the number of biology teacher candidates indicating the organ/structure in the research (f) and the ratio of biology teacher candidates indicating the organ/structure (%) are given in separate columns in the tables.

According to **Table 1**, the most frequently drawn organs/structures are the heart (94%), arteries (81%) and venules (81%), while the less frequently drawn organs/structures are lungs (41%), Blood (38%) and Capillaries (25%). Learning the human circulatory system, like learning many other biological concepts, is challenging. (Arnaudin & Mintzes, 1985; Sungur & Tekkaya, 2003).

As seen in **Appendix 1-2**, while most of the biology teacher candidates who were asked to draw the organs and structures of the circulatory system included the heart, arteries and veins in their drawings, they gave very little space to the lungs, capillaries and blood. Also, the shape of the heart is mostly drawn in the form of love.

Borazan (2008), Çobanoğlu and Bektaş (2012), analyzed students' drawings on subjects such as the shape of the heart, the location of the veins in our body, the location of the heart in our body, the function of the heart, the meaning of clean and dirty blood, the purpose and place of large and small blood circulation, blood circulation. It has been determined that there are misconceptions about the subject. It has been stated that the majority of these misconceptions in students are due to the fact that the subject of the circulatory system includes abstract concepts, while some misconceptions arise from their teachers, textbooks and education programs. Again, since the names and functions of the organs of other systems were not learned scientifically correctly, it was stated that there may have been misconceptions about the organs in the circulatory system and their functions. Bahar et al. (2008), revealed the level of understanding of science teacher candidates about the internal structure of the heart by having them draw. When the drawings of the science teacher candidates were analyzed, it was revealed that most of them had misconceptions in terms of the internal structure of the heart and they also had insufficient knowledge.

In addition to the above, each drawing made by the biology teacher candidates was examined in detail in terms of structural features and the findings are presented below (**Table 2).**

Looking at **Table 2**, it is seen that the most frequent atrium and ventricle structures of the heart are drawn (75%), the pulmonary veins (75%) are the most drawn in the veins, and the aorta (88%) is the most drawn in the arteries, and the O2-rich blood and CO2- rich blood (56%) is drawn in the blood. It is seen that bronchi and bronchioles (25%) are drawn in the lungs. S.A. Node, A.V. Node, Purkinje Fibers and Bundle Branches (6%) are drawn in the heart.

As seen in **Appendices 3, 4,** and **5**, while most of the biology teacher candidates who were asked to draw in detail in terms of the organs and structures of the circulatory system included the atriums, ventricules, aorta, pulmonary vein and pulmonary artery in their drawings, they gave very little space to the capillaries, lungs, blood cells and impulse generation structures. They drew the circulatory system, but they did not consider the role of the lungs, but only the heart. Also, there are incorrect drawings in the places of organs and structures of the circulatory system. Another teacher candidate confused the left and right parts of the heart (**Appendix 4**).

Gül (2011) asked the following question to her students in her study "What are the structures that produce impulses in the heart?" In response to the question asked, students; "neurotransmitter substances (12.82%)", "sensory nerves, somatic nerves, parasympathetic nerves (2.56%)", "brain (3.85%)", "caffeine, nicotine, etc. substances (3.85%)" and "neuron, synapse gap etc. (2.56%)" and they reflected the misconceptions that had settled in their minds. Michael et al. (2002) and Sungur et al. (2001) also stated in their study that the majority of students gave the answer "brain" to this question. These answers reveal students' misconceptions by relating the subject to the subject with their knowledge about the nervous system, rather than stating that the impulse in the heart is produced by the SA node (sinoatrial node). Gül (2011), Michael et al. (2002) and Sungur et al. (2001) concluded in their studies that students do not have enough knowledge about the circulatory system. In their study on the circulatory system, Arnaudin and Mintzes (1985) determined that students have misconceptions about blood circulation at all levels of the education system. In addition, they found that they did not understand concepts such as the structure of the blood and the circulatory system, the direction of blood flow, and they did not have enough information about how the lungs supply oxygen to the blood.

For the second research problem, the blood flow order presented, drawings were classified by using the same stages Biolgy of Campbell et al. (2016). It was determined how well the biology teacher candidates comply according to this stage, their percentages were taken in terms of each stages (**Table 3**).

Teacher candidates are responsible to drawing how blood circulated in the pulmonary and systemic circulations and how blood flows from artery through the arteriole, to the capillaries, return to venule to vein, and then back to the heart. Prospective biology teachers have demonstrated that the function of the heart pumps blood in two separate ways, and some participants have drawings of a correct relationship between the heart and lungs. We can conclude that the participants who drew the circulatory system in this way truly understood the heart as a pump. Many people know that the heart's function is to pump blood; however, some did not perceive that the heart was pumping blood in two separate ways. In fact, pre-service teachers tried to make sense of the circulation of blood throughout the body by drawing a circular path. However, most participants also have a drawing that includes an incorrect relationship between the heart and lungs. This drawing is inconsistent with a real understanding of the heart's role as a pump. Since the lungs cannot pump blood, blood cannot go from the lungs to the toe; only the heart has this capacity (López-Manjón & Postigo, 2005). However, the participants in this study were not aware of this error. The study by Chi et al. (1989) revealed that students had difficulty in stating the purpose of the lung and the number of circulation cycles. Pelaez et al. (2005) found that pre-service teachers had difficulties in perceiving some concepts. 70% of primary school teacher candidates could not understand large and small blood circulation, 30% were confused about blood vessels, 55% had misconceptions about gas exchange, and 19% had difficulty understanding gas conduction and 20% lung functions. Arnaudin and Mintzes (1985, 1986) asked students, "What path does blood follow when leaving the heart?" Only 7-15% of students chose the scientific model: heart-foot-heart-lung-heart. These students largely incorporated the lungs into the circulatory system as their age and teaching level increased, but they got it wrong.

The four-chambered human heart, containing all blood vessels, works according to a 'double circulatory system'. The pulmonary circulation separates clean blood from polluted blood through the lungs. Systemic circulation is the blood circulating throughout the body, taking the clean blood and returning the dirty blood to the heart (Cheng & Gilbert, 2015). However, it can be seen that the all of participants who drew lungs had a representation in which the capillaries covering the entire respiratory surface of the lung were not included (**Appendices 6** and **7**). This is where the blood delivers carbon dioxide to the lungs and takes up oxygen. At the system level, pre-service teachers are aware of the main function of the circulatory system, namely the transport and exchange of blood. However, at the organ level, pre-service teachers' associations with the structures of the lungs are lacking. Previous studies have revealed that students' understanding of the human circulatory system can be problematic. For example, by looking at students' drawings, it has been found that some believe the blood contains a drop of blood that circulates throughout the body before returning to the heart. They failed to grasp the importance of the pulmonary circulation (Arnaudin & Mintzes, 1985; Pelaez et al., 2005).

Moreover, it can be seen that the most of participants had a representation in which blood goes from the heart to the body lower parts and then returns to the heart. However, the very few of participants had a representation in which blood goes from the heart to the body upper parts and then returns to the heart. As if the candidates thought that the heart only pumps blood to the lower part of the body and did not draw the path of blood flow to the upper part of the body. In addition, it has been drawn that the blood does not follow a direct path from the heart to the target organ; on the contrary, it follows a circular path to other parts of the body before returning to the heart when leaving the heart (Appendix 8-9). An incorrect association has been established between the heart and lungs. This means a misconception about the heart's role as a pump. Borazan (2008) had students make drawings about the circulatory system and the following situations were observed: Systemic circulation was drawn below the heart and pulmonary circulation was above the heart. Systemic circulation was only drawn on the body. Systemic circulation and pulmonary circulation are drawn everywhere except arms, legs and head. The veins are drawn without being distributed all over the body.

In the drawings obtained from Özgür (2013)' study; the systemic and pulmonary circulation are independent of each other and occur in different parts of the body. Pulmonary circulation takes place in the upper part of the body and systemic circulation takes place in the lower part of the body. All structures of the human circulatory system should show very clearly the spatial position and gross appearance of the heart, lungs, and some blood vessels leading to the upper and lower parts of the body (Cheng & Gilbert, 2015). The scientific path where an artery leaves the heart and divides into secondary pathways, reaches the capillaries of the target organ and returns to the heart via the veins can be called the central model. However, some participants drew a different route, where blood did not follow a direct route from the heart to the target organ and returned to the heart.

Given the differences in ways the teacher candidates drew the blood flow diagram, perhaps not surprisingly, participants connected the pulmonary artery carrying dirty blood only to the right lung, and they connected the pulmonary vein carrying clean blood only to the left lung. It's as if the right lung is getting dirty blood and the left lung is sending clean blood to the heart (**Appendices 10** and **11**). In this case, a parallel running of an artery and a vein was drawn in the blood flow chart, and arteries and veins were connected to the heart and extended to other parts of the body. In fact, contraction of the right ventricle pumps blood to the lungs through the pulmonary arteries. The blood comes from the capillary beds in the left and right lungs to the left atrium of the heart through the pulmonary veins to the left atrium. Özgür (2013) observed in student drawings that while clean blood circulates on the right side of the body, clean blood circulates on the left side of the body. Clean blood circulates on the left side of the body, and unclean blood circulates on the right side of the body. In reality, clean and unclean blood is everywhere in the body. For this reason, it is wrong to show dirty blood only on the right side and clean blood only on the left side (Güngör & Özgür, 2009). Gençay (2016) examined and compared the pre- and post-education misconceptions of 6th grade students about the concept of blood circulation and found that the students could not adequately comprehend the content of clean and dirty blood, could not visualize where and how the dirty blood was cleaned in their minds, experienced various imbalances and reported some phenomena showed that they were misconfigured.

One reason for difficulty is the necessity of an integrated understanding of the different representations of the system when learning about the circulatory system. These include diagrams representing, for example, the four-chambered heart, the blood vessel system in the human body, the blood flow in the pulmonary and systemic circulation, the differences of arteries, veins, and capillaries. Arnaudin and Mintzes (1985, 1986) concluded that of all the different concepts of the circulatory system analyzed, the circulatory model is one of the most difficult to change. In this study, a diagram in science course textbooks was used and it was seen that many students' interpretations of this diagram contradicted scientific knowledge. Although the sample of the research consists of biology teacher candidates, it is seen that all misconceptions of the students are reinforced with the help of such materials in the science textbooks.

The teacher candidates could show with arrows that the blood coming from the lungs and aorta artery first passes from the atria to the ventricles and then disperses to the whole body but the drawings showed that the pulmonary artery of the candidates carried clean blood, and the pulmonary veins carried dirty blood (Appendix 12). Some of the misconceptions identified on this subject are “clean blood is carried in the pulmonary artery”. Here, it is seen that the teacher candidates confuse the vessels that bring blood to and from the heart, and generally think that the arteries carry clean blood and the veins carry dirty blood. These misconceptions were also revealed in the studies of Kete (2006), Sezen and Çimer (2009), which showed that very few teacher candidates have knowledge about the functions of pulmonary arteries and veins, which are exceptional cases in arteries and veins. It was emphasized by Canpolat et al. (2004) that this might be due to the over-generalization of concepts by students.

Conclusion and Recommendations

Understanding the human circulatory system is more difficult than teachers and education researchers think. Given the difficulty of learning, it is not surprising that students and even pre-service teachers advocate structures and blood flow that do not support the functions of the circulatory system.

This research is a study that reveals how pre-service teachers might have drawn the structures and organs related to the circulatory system and the blood flow between them. In the light of the findings obtained from this research, it is seen that pre-service teachers have some deficiencies and misconceptions about the blood circulation system. Although this result is not different from those found in previous studies, it supports what has been reported in the literature about students’ understanding of the human circulatory system.

This study reported teacher candidates’ conceptions of the human double circulation. While teacher candidates are learning new information and concepts, they have difficulties in combining them with their mental structures. Sometimes erroneous combinations were seen; because of sometimes learning by rote occurs. This leads to misconceptions. One of the important reasons why meaningful learning does not occur is the learning and teaching methods used.

In order to understand scientific ideas such as how the circulatory system facilitates the exchange of substances in organs such as the lungs, pre-service teachers should be encouraged to use pictures when appropriate. Drawing can form the basis for teachers and trainee teachers to assess their understanding. More research should be done to inform science teachers about how to have better practice in drawing. Specifically, teachers may want to help trainees understand that parallel work of arteries and veins does not exactly replicate the location of veins in the human body in teaching blood flow charts. In addition, pre-service teachers should learn how the ideas represented in the diagram relate to blood flow in the human body or body organs.

While textbooks are specifically pointed out as the cause of misconceptions in students, teachers, who are the source of information transfer, are also cited as the most important reason for misconceptions in students. In particular, identifying the current misconceptions in teachers will perhaps ensure that these misconceptions are minimized during their training, and therefore, when they become teachers, they will be able to educate their students in a way that will have the least misconceptions. At this point, more comprehensive studies are needed to identify and eliminate teachers' misconceptions. In addition, identifying misconceptions in the textbooks and correcting the textbooks after this detection will prevent book-related misconceptions.

Contemporary teaching techniques to be developed to eliminate misconceptions about the circulatory system are of great importance here. Considering that the circulatory system contains many abstract concepts, it is extremely important to present the subjects to students using all kinds of visual and audio materials during the teaching process and thus provide concrete learning. Many studies supporting this result show that concept maps, conceptual change texts, concept networks, meaning analysis tables, audio-visual tools, etc. can be used in eliminating students' misconceptions showing that its use positively affects learning. Therefore, if biology teachers prioritize the use of such materials in their lesson plans, they can minimize students' misconceptions.

References

Arnaudin, M. W. & Mintzes, J. J. (1985). Students' alternative conceptions of the human circulatory system: A cross-age study. *Science Education*, 69(5):721-33. DOI: https://doi.org/10.1002/sce.3730690513

Arnaudin, M. W. & Mintzes, J. J. (1986). What Research Says: The Cardiovascular System: Children's Conceptions and Misconceptions. Science and Children, 23(5):48-51.

Bahar, M., Özel, M., Prokop, P. & Uşak, M. (2008). Science student teachers' ideas of the heart. *Journal of Baltic Science Education*, 7:78-85.

Baysen, E., Güneyli, A. & Baysen, F. (2012). Kavram öğrenme-öğretme ve kavram yanilgilari: fen bilgisi ve türkçe öğretimi örneği [Concept learning-teaching and misconceptions: An example of science and Turkish teaching]. *International Journal of New Trends in Arts, Sports & Science Education (IJTASE)*, 1(2):108-117.

Behrendt H., Dahncke H., R., Gräber W., Komorek M., Kross A. & Reiska P. (2001). Research in science education - past, present, and future. Springer Science & Business Media. ISBN: 2731-3786. DOI: https://doi.org/10.1007/0-306-47639-8

Bennett, J. (2003). Teaching and Learning Science: A Guide to Recent Research and Its Application. London: Continuum. ISBN: 0-8264-6527-7.

Borazan, İ. (2008). Kavram yanılgısı ve çoklu zeka alanlarının ilişkilendirilmesine dayalı bir öğretimin kavram yanılgılarının giderilmesindeki etkisinin incelenmesi: Dolaşım sistemi örneği [Examining the effect of an education based on associating misconceptions and multiple intelligence areas in eliminating misconceptions: Circulatory system example]. Master's thesis, Balıkesir University, Balıkesir.

Brown, M. H., & R. S. Schwartz. (2009). Connecting Photosynthesis and Cellular Respiration: Preservice Teachers' Conceptions. *Journal of Research in Science Teaching*, 46:791-812. DOI: https://doi.org/10.1002/tea.20287

Canpolat, N., Pınarbaşı, T., Bayrakçeken, S., & Geban, Ö. (2004). Kimyadaki bazı yaygın yanlış kavramalar [Some common misconceptions in chemistry]. *Gazi Üniversitesi Gazi Eğitim Fakültesi Dergisi*, 24(1):135-146.

Cheng, M. M., & Gilbert, J. K. (2015). Students' Visualization of Diagrams Representing the Human Circulatory System: The use of spatial isomorphism and representational conventions. *International Journal of Science Education*, 37(1):136-161. DOI: https://doi.org/10.1080/09500693.2014.969359

Campbell, N. A., Reece, J., Ury, L. A., Cain, M. L., Wasserman, S., & Minorsky, P. (2016). Campbell Biology. Eleventh Editon. Publisher: Pearson. ISBN: 978-0135188743.

Chi, M. T. H. (2005) Commonsense conceptions of emergent processes: Why some misconceptions are robust. *The Journal of the Learning Sciences*, 14(2):161-199. DOI: https://doi.org/10.1207/s15327809jls1402_1

Çardak, O., & Dikmenli, M. (2018). Ortaokul öğrencilerinin sindirim sistemi hakkındaki düşüncelerinin çizim tekniği ile incelenmesi [Examining secondary school students' thoughts about the digestive system using drawing technique]. III. INES Education and Social Science Congress, Antalya, April 28.

Çobanoğlu, E. O., & Bektaş, H. (2012). Kavramsal değişim metinlerinin ilköğretim 6. sınıf öğrencilerinin dolaşım sistemi konusundaki kavram yanılgılarının giderilmesine etkisi [The effect of conceptual change texts on eliminating 6th grade primary school students' misconceptions about the circulatory system]. X. Science and Mathematics Education Congress, Niğde, June 27.

Dempsey, B. C., & Betz, B. J. (2001). Biological drawing: A scientific tool for learning. *The American Biology Teacher*, 63(4):271-279. DOI: https://doi.org/10.2307/4451099

Driver, R. (1988). Changing Conceptions. Tijdschrift voor Didactiek der B-wetenschappen, 6(3):161-197.

Driver, R., & Easley, J. (1978). Pupils and paradigms: A review of literature related to concept development in adolescent science students. *Studies in Science Education*, 5(1):61-84. DOI: https://doi.org/10.1080/03057267808559857

Gençbay, T. (2016). 6. sınıf öğrencilerinin kan dolaşımı ile ilgili düşüncelerinin analizi [Analysis of 6th grade students' thoughts about blood circulation] Master's thesis, Ondokuz Mayıs University, Samsun.

Gül, Ş. (2011). 5E modeline dayali olarak hazirlanan ders yaziliminin öğrencilerin başarilarina, tutumlarina ve kavram yanilgilarinin giderilmesine etkisi [The effect of course software prepared based on the 5E model on students' achievements, attitudes and eliminating misconceptions]. Ph.D.diss., Atatürk University, Erzurum.

Gül, Ş., & Özay Köse, E. (2021). Lise öğrencilerinin hücre ve organelleri konusundaki temel kavramlara yönelik bilgi düzeylerinin öğrenci çizimleri yoluyla belirlenmesi [Determination of high school students' knowledge levels of basic concepts about cells and organelles through student drawings]. *Atatürk Üniversitesi Kazım Karabekir Eğitim Fakültesi Dergisi*, 42:367-390. DOI: https://doi.org/10.33418/ataunikkefd.734585

Güngör, B., & Özgür, S. (2009). İlköğretim beşinci sınıf öğrencilerinin sindirim sistemi konusundaki didaktik kökenli kavram yanılgılarının nedenleri [Reasons for didactic-based misconceptions about the digestive system of fifth grade primary school students]. *Necatibey Eğitim Fakültesi Elektronik Fen ve Matematik Eğitimi Dergisi*, 3(2):149-177.

Kete, R. (2006). 6. sınıf fen bilgisi biyoloji konularında kavram yanılgıları [Misconceptions about 6th grade science and biology subjects]. *Dokuz Eylül Üniversitesi Buca Eğitim Fakültesi Dergisi*, 19:63-70.

King, C. J. H. (2009). An analysis of misconceptions in science textbooks: Earth science in England and Wales. *International Journal of Science Education*, 32:565-601. DOI: https://doi.org/10.1080/09500690902721681

Kumandaş, B., Ateskan, A., & Lane, J. (2019). Misconceptions in biology: A meta-synthesis study of research, 2000–2014. *Journal of Biological Education*, 53(4):350-364. DOI: https://doi.org/10.1080/00219266.2018.1490798

Liew, C. W., & Treagust, D. F. (1995). A predict-observe-explain teaching sequence for learning about students' understanding of heat and expansion of liquids. *Australian Science Teachers' Journal*, 41(1):68-71.

López-Manjón, A., & Angón, Y. P. (2009). Representations of the human circulatory system. *Journal of Biological Education*, 43(4):159-163. DOI: https://doi.org/10.1080/00219266.2009.9656176

Marioni C. (1989). Aspect of Srudent's Understanding in Classroom Setting: Case Studies on Motion and Intertia. *Physics Education*, 24: 273-277. DOI: https://doi.org/10.1088/0031-9120/24/5/307

Matthews, M. R. (1998). In defence of modest goals when teaching about the nature of science. *Journal of Research in Science Teaching*, 35:161-174. DOI: https://doi.org/10.1002/(SICI)1098-2736(199802)35:2<161::AID-TEA6>3.0.CO;2-Q

Michael, J.A., Wenderoth, M.P., Model, H.I., Cliff, W., Horwitz, B., & McHale, P. (2002). Undergraduate's understanding of cardiovascular phenomena. *Advances in Physiology Education*, 26(2):72-84. DOI: https://doi.org/10.1152/advan.00002.2002

Novak, J. D., & Gowin, D. B. (1984). Learning how to learn. New York: Cambridge University Press. DOI: https://doi.org/10.1017/CBO9781139173469

Novak, J. D., & Musonda, D. (1991). A twelve-year longitudinal study of science concept learning. *American Educational Research Journal*, 28(1):117-153. DOI: https://doi.org/10.3102/00028312028001117

Nugraha, I. (2018). The use of drawing as an alternative assessment tool in biology teaching. *In Journal of Physics: Conference Series*, 1013:1,012016. IOP Publishing. DOI: https://doi.org/10.1088/1742-6596/1013/1/012016

Özgür, S. (2013). The Persistence of Misconceptions About the Human Blood Circulatory System Among Students in Different Grade Levels. *International Journal of Environmental and Science Education*, 8(2):255-268. DOI: https://doi.org/10.12973/ijese.2013.206a

Özsevgeç, L. C. (2007). What do turkish students at different ages know about their internal body parts both visually and verbally? *Journal of Turkish Science Education*, 4(2):31-44.

Patrick, P. G., & Tunnicliffe, S. D. (2010). Science teachers' drawings of what is inside the human body. *Journal of Biological Education*, 44(2):81-87. DOI: https://doi.org/10.1080/00219266.2010.9656198

Pridmore, P., & Bendelow, G. (1995). Images of health: exploring beliefs of children using the'draw-and-write'technique. *Health Education Journal*, 54(4):473-488. DOI: https://doi.org/10.1177/001789699505400410

Prokop, P., & Faněovičová, J. (2006). Students'ideas about the human body: do they really draw what they know. *Journal of Baltic Science Education*, 5(10):86-95.

Reiss, M. J., & Tunnicliffe, S. D. (2001). What sorts of worlds do we live in nowadays? Teaching biology in a post-modern age. *Journal of Biological Education*, 35(3):125-129. DOI: https://doi.org/10.1080/00219266.2001.9655760

Reiss, M. J., Tunnicliffe, S. D., Andersen, A. M., Bartoszeck, A., Carvalho, G. S., Chen, S. Y., ... & Van Roy, W. (2002). An international study ofyoung peoples' drawings of what is inside themselves. *Journal of Biological Education*, 36(2):58-64. DOI: https://doi.org/10.1080/00219266.2002.9655802

Riche, R.D. (2000), Strategies for Assisting Students Overcome Their Misconceptions in High School Physics. Memorial University of Newfoundland Education. 6390.

Rotbain, Y., G. Marbach-Ad, & R. Stavy. (2008). Using a Computer Animation to Teach High School Molecular Biology. *Journal of Science Education and Technology*, 17:(1):49-58. DOI: https://doi.org/10.1007/s10956-007-9080-4

Sezen, G., & Çimer, A. (2009). Fen bilgisi öğretmen adaylarının insanda dolaşım sistemi konusundaki kavramları anlama seviyelerinin kavram haritası ve kelime ilişkilendirme testi ile belirlenmesi [Determination of science teacher candidates' understanding levels of concepts on the human circulatory system using concept map and word association test] International Educational Research, Çanakkale Onsekiz Mart University, Çanakkale.

Stepans, J. (1996). Targeting Students' Science Misconceptions: Physical Science Concepts Using the Conceptual Chance Moldel. Riverview, Fla: Idea Factory. ISBN: 1891022075.

Sungur, S., Tekkaya, C., and Geban, Ö. (2001). The contribution of conceptual change texts accompanied by concept mapping to students' understanding of the human circulatory system. *School Science and Mathematics*, 101(2):91-101. DOI: https://doi.org/10.1111/j.1949-8594.2001.tb18010.x

Sungur, S., & Tekkaya, C. (2003). Students' achievement in human circulatory system unit: The effect of reasoning ability and gender. *Journal of Science Education and Technology*, 12(1):59-64. DOI: https://doi.org/10.1023/A:1022111728683

Yağbasan R. ve Gülçiçek Ç. (2003). Fen öğretiminde kavram yanilgilarinin karakteristiklerinin tanimlanması [Defining the characteristics of misconceptions in science teaching]. *Pamukkale Üniversitesi Eğitim Fakültesi Dergisi*, 13(1):102-120.

Yip, D. Y. (1998). Teachers' misconceptions of the circulatory system. *Journal of Biological Education*, 32(3):207-215. DOI: https://doi.org/10.1080/00219266.1998.9655622

Received: February 27, 2024
Revised: March 5, 2024
Accepted: March 14, 2024

Biology Teacher Candidates Drawings about Circulatory System

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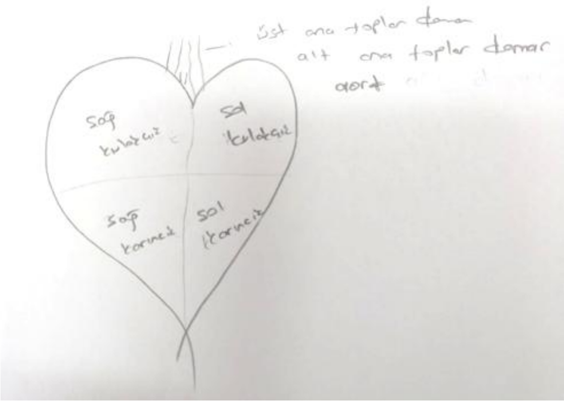
APPENDICES 1-12

1.



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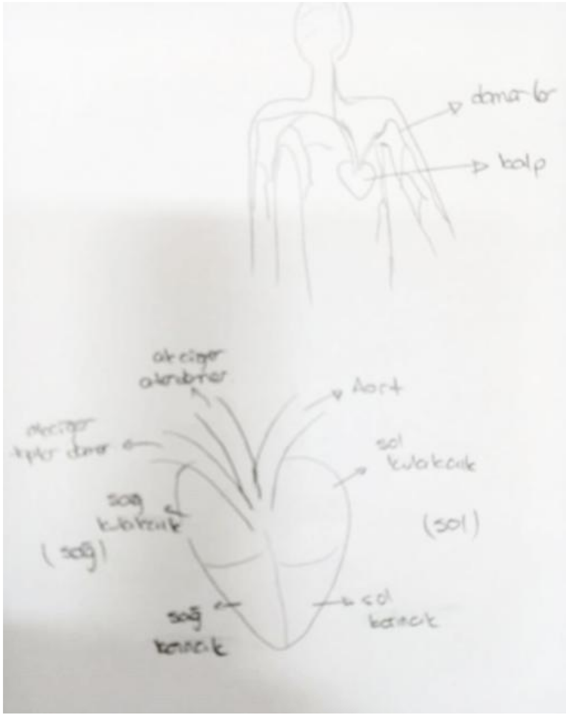

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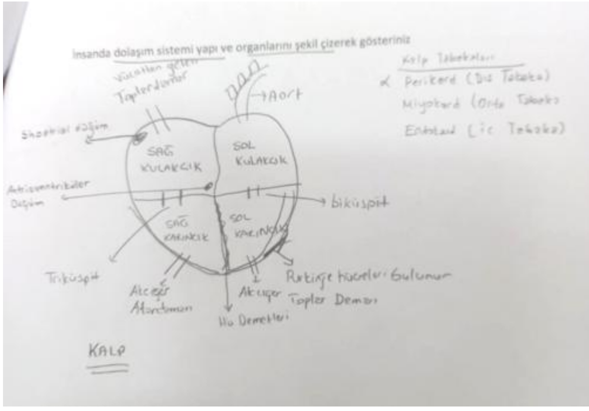
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Miyokard (Orta Tabaka)
Endokard (İç Tabaka)
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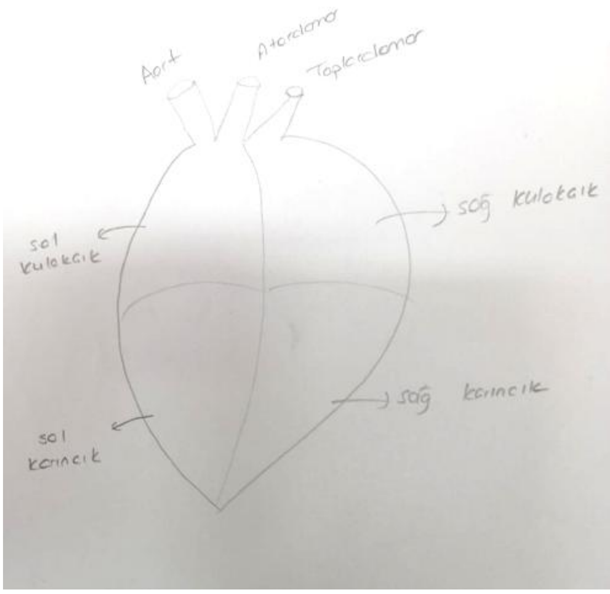
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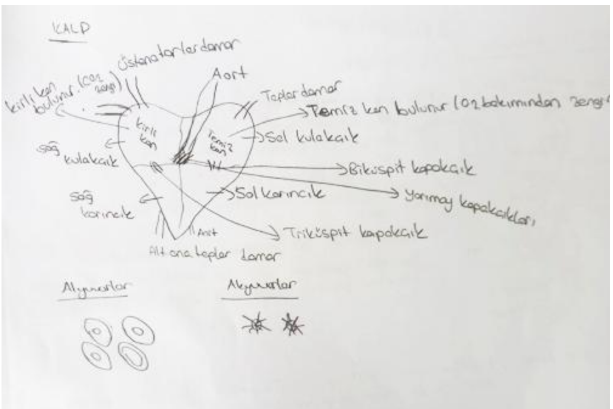
5.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Yarımay kapakçıkları
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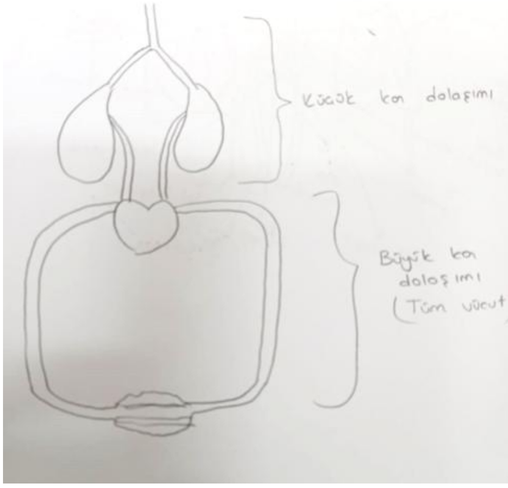
6.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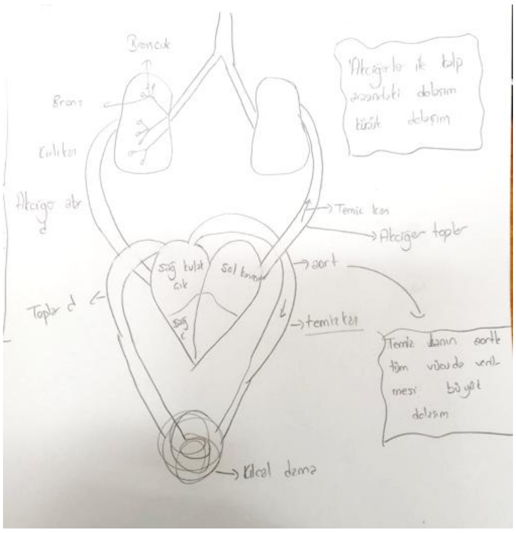
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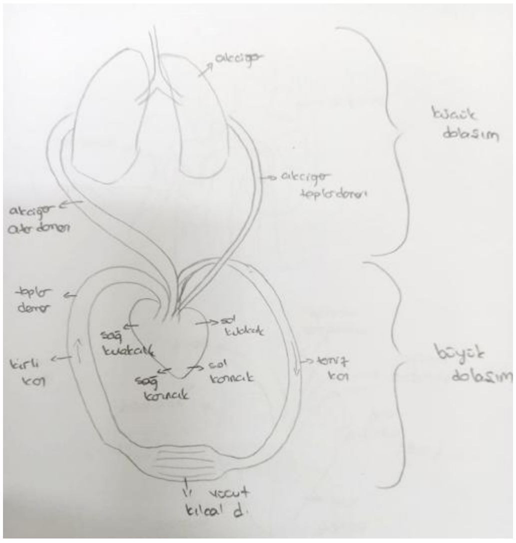
Kılcal damar

8.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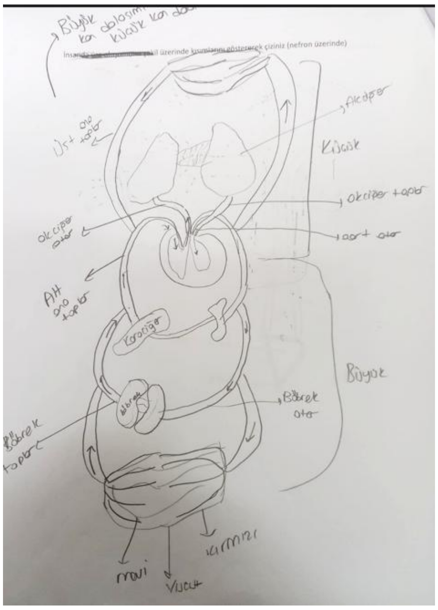
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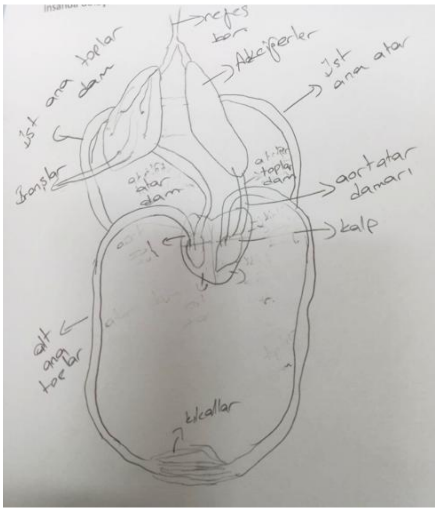
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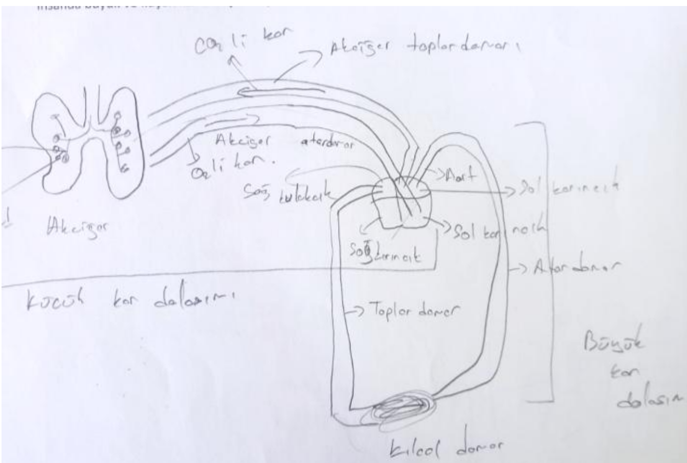
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Toplar damar
Büyük kan dolaşımı
kılcal damar

ORIGINAL ARTICLE

Comprehensive Practice Education via "Cloud-Based Study Tours": A Case Study of the Comprehensive Practice Curriculum in the Tianfu New District, Sichuan Province, China

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***Abstract**: Comprehensive practice education is an integral part of the basic education curriculum, aiming to train students to connect textbook knowledge with real-world life through hands-on manipulations and in-person experiences in off-campus settings. In response to the challenges arising in the current enactment of the comprehensive practice curriculum in Chinese county-level schools, the Tianfu New District Educational Science Institute of China's Sichuan Province developed the "cloud-based study tour" model to leverage local cultural and social resources to advance comprehensive practice education. Strategies, such as digital empowerment and curriculum development partnerships, were adopted. This article focuses on expounding on the positive roles of the "cloud-based study tour" in supporting regionally balanced, high-quality practical education by fully utilizing digital technologies and partnerships in curriculum development.*

Science Insights Education Frontiers 2024; 23(2):3799-3809
DOI: 10.15354/sief.24.or623

How to Cite: Yang, T. (2024). Comprehensive practice education via "cloud-based study tours": A case study of the comprehensive practice curriculum in the Tianfu New district, Sichuan province, China. Science Insights Education Frontiers, 23(2):3799-3809.

***Keywords**: Cloud-Based Study Tour, Comprehensive Practice Education, Digital Education, Curriculum Development Partnership, China*

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Conflict of Interests: *None*

AI Declaration: *The author affirms that artificial intelligence did not contribute to the process of preparing the work.*

CHINA's *Compulsory Education Curriculum Program and Course Standards 2022* emphasize the importance of incorporating labor education and social practice into the curriculum framework, giving students the opportunity to learn by doing, applying, and creating, and helping them experience the complete learning cycle of discovering issues, solving problems, constructing knowledge, and applying knowledge (State Council of China, 2022). The school's comprehensive practice (CP) curriculum is the main avenue for children's practical education, which is of vital importance for their all-round development (Xue, 2023). Nevertheless, CP education in current China faces challenges regarding the popular conception of its significance, resource availability, and technological backing. The issue of how to utilize social resources, especially local cultural resources, and orderly incorporate them into school curricula to aid students in realizing knowledge transfer in real-world and open education settings is pending more practical explorations.

The study tour is a meaningful form of CP education activity that allows primary and secondary school students the opportunity to experience the beauties of nature and the attractions of traditional cultures (Luo, 2023). The Tianfu New District Educational Science Institute in China's Sichuan Province developed a technology-enabled modality of practical instruction dubbed the "cloud-based study tour." It is a paradigmatic practice of fully leveraging natural resources, cultural relics, and technological innovations to support the holistic development of students and the regionally balanced, high-quality development of education. This article lays out the issues with the implementation of the CP curriculum in Chinese county-level schools and expounds on the roles of the cloud-based study tour in enacting CP education, as well as delineating its educational outcomes using a genuine example.

Challenges in the Implementation of the Comprehensive Practice Curriculum in Chinese County-Level Schools

According to the Ministry of Education of China (2024), Chinese basic education is currently undergoing a transition from the expansion of education scale to high-quality development. Educators at all levels have the responsibility to contribute to building a high-quality education system to support the sustainable socioeconomic development of the nation. The high-quality development of county-level education as the grassroots component of Chinese basic education is of extraordinary significance for the overall advancement of the system. In *The Modernization of Chinese Education 2035*, the State Council of China (2019) announced the goal of realizing balanced, high-quality compulsory education in at least 95% of Chinese county regions by the year 2035. To reach this goal, it is imperative to ensure the successful implementation of the national curriculum program and enhance the instruction level of non-standardized courses like "comprehensive practice" in county-level schools, in addition to promoting a balanced allocation of educational resources (Li, 2022). Practical education plays a crucial role in fostering students' manipulation skills and creative ability (Xue, 2023); a complete practical education curriculum is a precondition for student all-round development. Nonetheless, the enactment of the CP curriculum in county-level schools is less smooth than expected. A survey of CP education in the Tianfu New District of Sichuan Province finds that:

1 There are considerable disparities in CP education standards between urban and rural schools within the county region. Urban schoolteachers have easier access to a wide range of educational resources, enjoy ample training opportunities, and are more experienced in carrying out CP instruction. Conversely, their rural counterparts have limited exposure to practical education resources; as a result, they tend to be less proficient in activity design, the selection of instructional methods, and the use of modern technology in CP education (Yang & Lei, 2023). These disparities result in a significant gap in the quality of CP education between urban and rural schools, working against rural students in their development of practical skills.

2 There are also stark inter-school differences in attitudes towards CP education. Schools that give equal weight to traditional core subjects and the practical education curriculum typically offer students a wide variety of practical courses, which significantly boost students' overall competence. Others may undervalue the significance of the CP curriculum and neglect the investment in student practical education, leading to a lack of teaching staff specializing in practical education, a scarcity of necessary equipment, and the absence of practical training bases (Guo, 2023). Such inter-school divides are a severe impediment to the popularization of practical education.

The Significance of the "Cloud-Based Study Tour" for Addressing the Issues with CP Curriculum Implementation

The "cloud-based study tour" is a modality of technology-enabled practical instruction developed under the strategies of "technology empowerment" and "curriculum development partnership." By removing temporal and spatial constraints through the online and offline blended teaching method, the cloud-based study tour can integrate the resources of multiple stakeholders and convert diverse extra-curriculum materials, such as the local cultures, into engaging and educative curriculum subject matter. Its practice of leveraging natural resources, cultural relics, and technological innovations to support student holistic development is an innovative experiment in addressing the issues with the enactment of the CP curriculum.

Technological Empowerment for Supporting Balanced, High-Quality Development of Regional Education

Integration of Technology and Cultural Resources

The Tianfu New District Educational Science Institute set about experimenting with educational technologies in CP education in 2020. An educational technology research team of 30 teachers was established to explore the application of technologies, such as the network, live streaming, filming, digital editing, program directing, and software platforms, in practical education. After that, the environmental education group, humanities education group, and science and technology education group were set up, all together forming a regional CP education project team. Ten sessions of live STEM lessons were provided to students, free of charge, in 2020. Later, nearly 400 teachers joined to form a research team for the "cloud-based study tour" program and develop professional research mechanisms (**Figure 1**).

In 2021, the research team began to produce off-campus programs and make them public to more students through online platforms. So far, 10 sessions of outdoor lessons on popular science have been successfully broadcast live, including "Cloud-Based Bird Watching," "the Campus Plant Map," and "Clever Hands," among others. Particularly, the livestreaming lesson "Cloud-Based Bird Watching" in February 2021 engaged approximately 9000 students in the online interactive learning activity. In 2022, after consulting literature and experts in relevant fields, the research team made improvements to the curricular design of "online real-scenario-based tour plus offline inquiry-based autonomous learning," and this multi-terminal distance learning paradigm was officially named the "cloud-based study tour." Subsequently, the research team launched a series of CP lessons, including the "cloud-based study tour of Du Fu's Thatched Cottage" and "cloud-based study tour of Sanxingdui Museum," successfully engaging in the program more than 20 schools from Chengdu, Deyang, Meishan, and Ziyang Cities and Ganzi, Aba, and Liangshan Autonomous Prefectures and serving thousands of students, particularly in remote rural and ethnic minority areas.

In the context of digital transformation in education, the integration of technology and cultural resources has the potential to significantly ad-

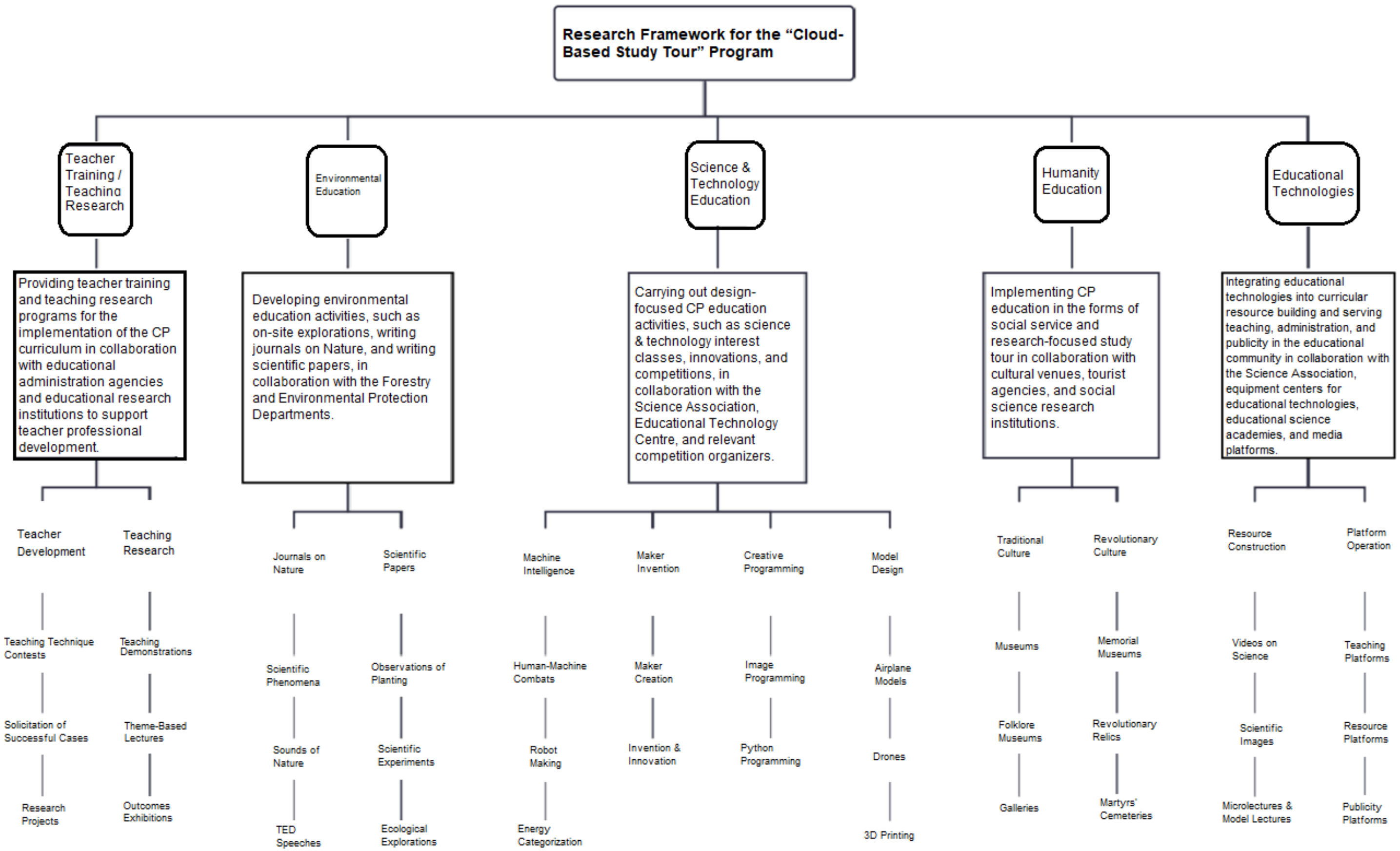

Figure 1. The Tianfu New District Educational Science Institute's Research Mechanism for the "Cloud-Based Study Tour" Program.

vance the balanced, high-quality development of education. The development and implementation of the "cloud-based study tour" program in Sichuan's Tianfu New District is an exemplary practice of this integration, giving full play to the educational roles of natural attractions and cultural heritages. This learning pattern not only exhibits the power of technology but also highlights the value of the cultural heritage in the region. By employing educational technologies, the Tianfu New District provides high-quality CP education for all students in urban, rural, and ethnic minority areas, successfully mitigating the uneven distribution of educational resources.

Blending Online and Offline Learning

Online and offline blended learning, as an instructional strategy, is of vital importance in the digital transformation of education. Practical education encourages students' transcending the time and space constraints of classroom learning and making their inquiry in-depth, boundless, and real-life-based (Liu, 2022). The online and offline blended learning method can well serve this purpose by combining real scenarios with virtual reality and "presence" with "distance," providing students with opportunities for boundless, mutually inspiring learning.

The "cloud-based study tour" program research team created a design that consists of three chief components in the sequence of "offline pre-class autonomous study," "online interactive study in a virtual classroom," and "offline artifact making." The student's "cloud-based study tour" is task-driven and will be assessed by their presentation of creative artifacts as learning products. The program design was developed into a practical learning platform, dubbed the "Center for Cloud-Based Study Tour," which provides generally applicable technological solutions, explicit learning procedures, and easy manipulation. The platform has become a paradigmatic pattern of CP education and an integrative tool that blends teaching, learning, and assessment.

Curriculum Development Partnership for Thorough Exploitation of Local Cultural Resources

In the past few years, the Tianfu New District Educational Science Institute has worked to establish a practical education community in collaboration with all stakeholders concerned, including environmental departments at all levels and cultural venues as well as urban, rural, and ethnic minority schools. This practical education community has placed high value on cross-agency partnerships in the development and implementation of the practical education curriculum, creating mechanisms for the sharing of resources and research outcomes. In partnership with all actors involved, the "cloud-based

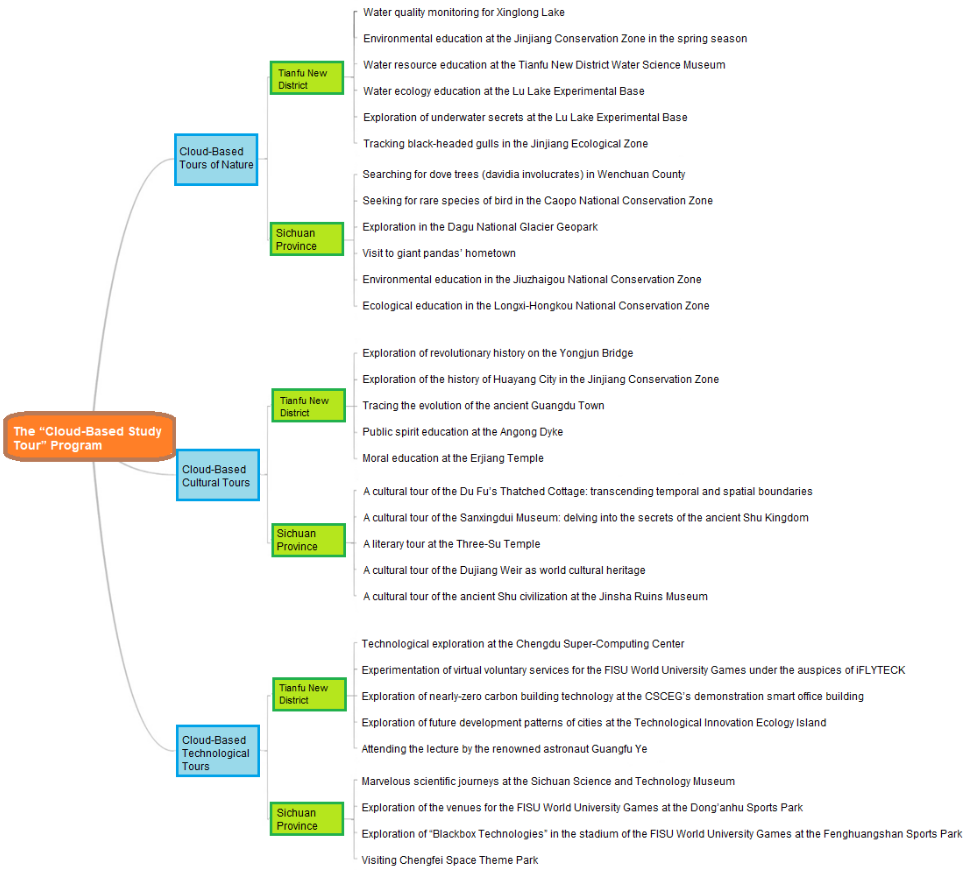

Figure 2. A Theme-Based Activity Framework for the "Cloud-Based Study Tour" Program.

study tour" research team of the Institute has developed a theme-based activity framework (**Figure 2**) for practical education activities that are in line with the requirements of the national CP curriculum at the basic education level.

In the said framework, the section on "cloud-based tours of nature" focuses on the environmental resources available in the Tianfu New District, which is projected to develop into a state-level "garden city," and in Sichuan Province, which has been historically acclaimed as a "blessed land." With "cloud-based tours of nature," students can easily access natural attractions such as Xinglong Lake, Luxi River, and Jinjiang Conservation Zone and visit landmark places like the National Giant Panda Park and Dagu Glacier. The livestreaming and recorded lessons enable them to experience, explore, and develop knowledge about nature. The program developers borrow learning substances from the geological and biological environments in these natural areas as students' research topics. After the "cloud-based tours of nature," junior students at primary schools must hand in their observation journals on nature, senior students at primary schools their research essays, and secondary school students their artifacts with environmental themes; regular selections and exhibitions are conducted based on students' study outcomes.

The section on "cloud-based tours of cultural venues" includes outstanding practical education projects like the "cloud-based study tour of Du Fu's Thatched Cottage: transcending temporal and spatial boundaries" and the "cloud-based study tour of Sanxingdui Museum: delving into the secrets of the ancient Shu Kingdom." Du Fu's thatched cottage and the Sanxingdui Museum's restoration workshop act as the classrooms for the enactment of these projects. More than 20 schools from the Tianfu New District have been engaged in them, and their students are required to go through the structured process of offline pre-class autonomous study, online livestreaming study tour, and offline extended research. This makes it possible for all remote terminal classes to take part in theme-based exploratory learning. In addition, each cultural study tour is guided by three teachers, who are the museum docent, the on-site teacher host, and the teacher at the terminal classroom. The "triple-teacher classroom" ensures that the practical education process is professional, engaging, and full of effective interactions.

The Cloud-Based Study Tour of Sanxingdui Museum: An Exemplary Practice of CP Education

To develop 2024's "cloud-based study tour of Sanxingdui Museum," the Tianfu New District Educational Science Institute's "cloud-based study tour" research team tapped into local cultural resources with the goal of fostering students' knowledge of ancient Shu civilization and traditional Chinese culture. There were 15 local schools contributing to the five-month development of the project.

For their "offline pre-class autonomous study," students from participating schools were provided with uniform handouts and required to complete pre-class assignments and hand them in on the "Center for Cloud-Based Study Tour" platform. In addition, practical education tutors at each school also created their own teaching materials to help students develop preliminary knowledge of the Sanxingdui civilization.

For the central stage of "online interactive study in a virtual classroom," Qing Li, head of the Qing Li Anchor Teachers Studio, and Junmin He, the leading docent at Sanxingdui Museum, co-designed the online teaching and co-hosted the lecture on site. Thus, the lecture combined the expertise of a museum specialist with that of a professional educator. In order to enable students to have an in-depth understanding of the significance of the historical archaeological discovery, the project team chose the restoration workshop of the museum as the livestreaming classroom. There were many online-offline interactive activities in the livestream, such as the "virtual simulation of archaeological excavation" and "naming cultural relics." Students from 15 schools experienced a collective classroom full of vitality, where the online interactions, such as the random selection of actors and Q&A, were embedded into the process and the teacher-student communication was seamless.

In the last stage of "offline artifact making," student participants, under the guidance of their respective teachers, worked to produce Sanxingdui-themed artifacts and presented them for online and offline exhibitions and selection. For instance, the 2019 class students at Tianfu No.7 Primary School made an artifact, dubbed "The Dream-Like Ancient Shu Kingdom," for their participation in the exhibition of "Sanxingdui Cultural Experience Space." They converted what they had learned in the preceding stages of the study tour into a tangible product, which represented an interactive space for a Sanxingdui cultural tour. This work won them a special prize in the Tianfu New District-based selection and was sent to the exhibition of "Chengdu City's Comprehensive Practice Education Achievements," where it was awarded a special prize again.

The "cloud-based study tour of Sanxingdui Museum," a paradigmatic project in the "cloud-based study tour" program, drew heavily on the Ba-Shu culture and generated significant practical education outcomes with its unique teaching design and marvelous content. By integrating online and offline learning, the project considerably enriched practical experiences and enhanced the exploratory capacities of the students. The smooth communication and resource sharing among the students from the 15 schools evidenced the role of CP education collaboration in alleviating educational inequality.

Conclusion

The "cloud-based study tour" program is a meaningful, innovative experiment in popularizing CP education in China's county regions. As a new practical education paradigm, it needs multifaceted support from all stakeholders, increased input of manpower and material resources, and intensified multi-agency partnerships in curriculum development. Furthermore, more theoretical and practical explorations of CP curricula in academia are necessitated, and research on the technological application in practical education should be strengthened to perfect programs like the "cloud-based study tour" to support balanced, high-quality development of education in China.

References

Guo, R. (2023). A Case Study of the Balanced Distribution of Compulsory Education Resources in Public Primary and Secondary Schools in S District of D City (master's thesis). Guangxi Normal University. Available at: https://link.cnki.net/doi/10.27036/d.cnki.ggxsu.2023.001490

Li, C. (2022). Optimizing the Monitoring and Evaluation System for the Development of Balanced Compulsory Education (doctoral dissertation). East China Normal University. DOI: https://doi.org/10.27149/d.cnki.ghdsu.2022.000306

Liu, T. (2022). The Educational Roles of Schools and Realization Paths (doctoral dissertation). Guangxi Normal University. DOI: https://doi.org/10.27036/d.cnki.ggxsu.2022.000009

Luo, T. (2023). Moral Education in the Senior Secondary Geography Study Tours in Guiyang City (master's thesis). Guizhou Normal University. Available at: https://link.cnki.net/doi/10.27048/d.cnki.ggzsu.2023.001359

Ministry of Education of China. (2024). Developing a High-Quality Education System as the Bedrock of National Rejuvenation. Available at: http://www.moe.gov.cn/jyb_xwfb/s5148/202403/t20240307_1118894.html

State Council of China. (2019). The Modernization of Chinese Education 2035. Available at: https://www.gov.cn/zhengce/2019-02/23/content_5367987.htm

State Council of China. (2022). The Compulsory Education Curriculum Program and Course Standards 2022. Available at: https://www.gov.cn/zhengce/zhengceku/2022-04/21/content_5686535.htm

Xue, M. (2023). The Development and Optimization of Study Tours Curriculum for Primary and Secondary Schools (master's thesis). Jiangnan University. DOI: https://doi.org/10.27169/d.cnki.gwqgu.2023.000611

Yang, H & Lei, W. (2023). Children from County Regions. Beijing: China Remin University Press.

Received: June 10, 2024
Revised: July 22, 2024
Accepted: July 29, 2024

REVIEW

Essential Elements of Principal Leadership: A Literature Review of the Leadership Qualities of Primary and Secondary Principals

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***Abstract**: Amidst ongoing educational reform around the world, the leadership qualities of primary and secondary principals have captured the increased interest of researchers. This article aims to explore the essential components of principal leadership by conducting a literature review of relevant research both in China and other countries. The survey finds that despite the variations in the definitions of principal leadership in different regions and at different times, there are still certain shared key elements in them. It summarizes the core qualities of principal leadership at the basic education level in terms of personal traits, the capacity to influence people, and the ability to make sustainable organizational improvements.*

Science Insights Education Frontiers 2024; 23(2):3811-3825
DOI: 10.15354/sief.24.re392

How to Cite: Chen, X., & Chen, H. (2024). Essential elements of principal leadership: A literature review of the leadership qualities of primary and secondary principals. Science Insights Education Frontiers, 23(2):3811-3825.

***Keywords**: Principal Leadership; Leadership Qualities; Primary and Secondary Principals; Literature Review*

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***Conflict of Interests**: None.*

***AI Declaration**: The authors affirm that artificial intelligence did not contribute to the process of preparing the work.*

Introduction

IN THE CONTEXT of ongoing reform in the education world, the development of basic education has garnered special attention in academia as well as among the general public. Primary and secondary principals, who play a central role in the development of their respective schools, have been required to take on increased responsibilities. Whether they can meet the ever-intensifying challenges is contingent on their leadership qualities (Yan, 2022). Principal leadership is a critical component of school governance, mediating institutional factors, such as the organizational structure, rules and regulations, and resource allocation, as well as cultural factors, such as school culture, values, and teacher-student relationships within the school (Wang, 2015). It can have significant influences on the efficiency of school management, teacher professional development, and student academic achievements (Veleti et al., 2023; Karadağ et al., 2015; He et al., 2024).

The study of principal leadership began in late 20th-century America. In the following decades, researchers have conducted multi-faceted investigations in this area. Walker and Hallinger (2015) synthesized five systematic literature reviews on principal leadership in East Asia and discerned three content patterns via thematic analysis: influences on principalship, principal leadership practices, and principal development. Goldring et al. (2016) conducted a comprehensive review of principal leadership assessment practices in the United States for a thorough understanding of the distinct practices of principal leadership assessment in various states. Arar et al. (2022) systematically surveyed research on Islamic-based educational leadership published between 1990 and 2021 to present the main themes incorporated in these studies and to reveal the developments in research on educational leadership and policy in the Islamic world. In addition to studies examining country- or territory-specific principal leadership, there have also been academic efforts to promote principal leadership research in a certain country by drawing on research results from foreign countries (Zhao & Zhou, 2017; Xu & Zhu, 2019). For example, to provide recommendations on enhancing Chinese principal leadership practices and school governance capability, Yan (2022) surveyed the theoretical constructs, structural models, and research methods in principal leadership studies in Western countries and explored the key elements and application scenarios of excellent principal leadership.

More in-depth research into and extensive practical explorations of principal leadership necessitate a clear definition of its essential components. Particularly, to evaluate the effects of principal leadership on other educational factors, it is necessary to develop appropriate assessment instruments to ensure the reliability and validity of research. Some researchers discovered that the practices of leadership assessment often lacked justification and documentation in terms of the utility, psychometric properties, and accuracy of the instruments, and that the main difficulty in assessing principal leadership was the identification of the dimensions that needed to be assessed (Goldring et al., 2016). At the same time, principal leadership is highly contextual (Arar et al., 2022), with its development being influenced by multiple factors, such as the social system, policies, and culture (Walker & Hallinger, 2015). As a result, it is challenging to unify the definition of principal leadership dimensions for different regions. Also, due to the continual evolution in the educational landscape and national policies across the years, the connotations of principal leadership are constantly changing. Recent years have witnessed the emergence of various conceptual frameworks or models for principal leadership. Each of them has its own features regarding the definition of dimensions and the model structure. Yet, they are not completely mutually exclusive but instead share some commonalities (Wang, 2015). Therefore, we contend that principal leadership in different contexts may have varied components but is bound to bear some common essential elements that deserve thorough exploration for further advancing the development of basic education.

Research Purpose and Questions

The present study aims to extract essential qualities of principal leadership from the existing body of literature to provide reference for researchers who are working to develop principal leadership assessment tools, for education administrators who are accountable for the planning of principal training and for primary and secondary school leaders who are committed to continuously improving their leadership capacity. Specifically, it addresses the following research questions:

RQ 1: What are the justifications for the definition of components of principal leadership by researchers from various regions?

RQ 2: What is the evolution trajectory of principal leadership amid the changes in times and education climates?

RQ 3: What are the commonalities shared by different studies in their judgment of the core qualities of principal leadership?

Research Methods and Process

We sourced literature from the Web of Science and China National Knowledge Infrastructure (CNKI), using “principal leadership,” “educational leadership,” “principal,” “models,” “indications,” and “qualities” as search terms. To ensure the academic quality of the included literature from the

CNKI, only articles published by journals listed in "A Guide to the Core Journals of China" and the "Chinese Social Science Citation Index" were included. All papers are from peer-reviewed journals. In order to retrieve studies of principal leadership from different periods, there were no time limits set for the publications. By the deadline of June 25th, 2024, 271 articles in Chinese and 403 ones in English had been obtained.

After removing duplicate articles, we further excluded those with (1) a focus on non-basic education principal leadership; (2) a lack of clear definition of components of principal leadership; (3) a discussion concentrating on the leadership of ordinary teachers and educational authorities; and (4) full text unavailable. The application of Rayyan was adopted in the screening and analysis of the articles retrieved. After selecting literature that was highly relevant to the topic in discussion, we also adopted the method of snowballing for literature complementation. Finally, 60 articles were included in our literature review, with 27 in Chinese and 33 in English.

A Comparison of the Definitions of Principal Leadership by Chinese and Foreign Researchers

Our review shows that there are differences in the definition of the components of principal leadership between Chinese and foreign researchers. First off, prominent is the influence of Confucianism-dominated traditional Chinese culture and values on Chinese researchers' conception of principal leadership. For instance, Ai and Zhao (2019) drew on traditional Chinese ideological notions, such as "prioritizing righteousness over personal interests," "moral integrity," "serving the public," and "alignment between knowledge and action," in constructing a principal leadership model that highlights three major components: value leadership that emphasizes benevolence and righteousness, moral leadership that requires both spiritual and behavioral integrity, and instructional leadership based on personal expertise and aspirations. Zhang (2023), drawing inspiration from the Confucian Analects, argued that principal leadership should incorporate self-development ability, the capacity to guide, and social skills. In the meantime, Chinese researchers are susceptible to the impact of running governmental policy when conceptualizing principal leadership. In response to the new requirements for the teacher's roles under the "competence-focused education" policy, Li et al. (2012) advanced a teacher development-centered principal leadership style, which prioritizes teacher professional development, pays attention to the teachers' emotional and attitudinal changes, and seeks a balance between normalizing teachers' educational behavior and stimulating their motivation for innovation. In addition, it is possible that certain research on principal leadership has been affected by both traditional culture and current education policies. For example, in the context of the Chinese government's advocacy of building a high-quality education system, Liu (2023) emphasized the traditional Chinese management concept of "serving as a role model for one's subordinates" in defining the roles of the school leader, who, in her mind, must act as an excellent example for ordinary teachers and provide professional guidance for them.

More often than not, researchers from outside China choose to justify their definition of the components of principal leadership with a certain leadership theory. For example, the theory of principal instructional leadership is frequently adopted in research on the core qualities of principal leadership (Emmanuel & Valley, 2021). Some researchers proposed evaluating the instructional leadership capability of principals in three dimensions: establishing the school mission, managing teaching plans, and creating a positive learning atmosphere (Hallinger & Murphy, 1985; Antoniou & Lu, 2018). Others opted to look at principal instructional leadership in five dimensions: developing the school's education specialties, raising the curriculum and teaching quality, promoting teacher professional development, improving the effects of adaptive learning, and optimizing teaching support (Lai & Lien, 2023; Aldighrir, 2024). Ahmad et al. (2023) added counseling skills to the conventional model of principal instructional leadership, arguing that the principal must have adequate communication skills in addition to educational expertise. Furthermore, other leadership theories, such as transactional leadership and context-based leadership, have also been employed in discussions about the dimensions of principal leadership (Bass et al., 2003; Kutz, 2008; Noman et al., 2017; Leithwood et al., 2019). In addition to the said leadership theories from the education world, some researchers have tried to draw on theories in the domain of business management (Berkovich & Hassan, 2023). For instance, Da'as (2016) discussed principal leadership in the dimensions of interpersonal communication skills, strategic capability, and cognitive ability on the basis of Mumford et al.'s (2007) leadership skills model.

Nevertheless, our review spotted a common research method adopted by domestic and foreign studies on principal leadership qualities: to gather information on distinguished principals through direct or indirect channels and extract valuable leadership skills from their specific practices (Chen & Yang, 2020; Kramer, 2023; Zeinabadi, 2023). Using research results from the International Successful School Principals Program (ISSPP), Hu (2022), a Chinese researcher, summarized key qualities for being a successful principal, such as the capacity to assist school members in reaching an agreed vision, to promote teacher professional development, to build constructive relationships with stakeholders, and to discern the development opportunities for the school. Norman et al. (2016) conducted a case study of a Malaysian school, which reveals that potent interpersonal skills, people-centered leadership, clear communication of visions and goals, focusing on student academic achievement, co-curricular activities, developing people, and creating a positive work environment are all vital constituents of successful principal leadership.

To sum up, the education policies, national culture, relevant leadership theories, and practical experiences of principals are all possible considerations for the definition of components of principal leadership. Chinese researchers are more likely to establish the dimensions of principal leadership from the standpoints of traditional culture and education policies, while their foreign counterparts show preferences for specific leadership theories as the justifications for their definition of principal leadership. Some studies have also pointed out that the same leadership theory may result in varied definitions of principal leadership dimensions in different countries or territories due to the disparities in the expected roles of the principal in differential places (Zhang, 2013; Zheng et al., 2017). In other words, principal leadership is highly contingent on its specific context.

The Evolutionary Trajectory of the Components of Principal Leadership

Our survey finds that the expected qualities of principal leadership vary as time changes and educational reform advances. In China, the recent socioeconomic transformation and education policy shifts find their expression in researchers' varying conceptions of principal leadership. Zhang (2007, 2009) argued that the early constructs of principal leadership typically included three aspects: directing organizational development, improving team efficacy, and building the bi-partite relationship between the principal and staff. In the context of the introduction of the "Double Reduction Policy" in recent years, which emphasizes the reduction of students' academic burden, the bi-partite relationship gives way to a tri-partite one that stresses the importance of the principal's attention to students' competence development in addition to that of the teaching staff and middle-level school cadres (Cheng & Zhang, 2023). Earlier, Shen and Sun (2014) defined principal leadership as the ability to use organizational resources to create an education environment that facilitates professional community-based cooperation, meaningful teacher-student interaction, and improvement of teaching quality, with the ultimate goal of enhancing students' academic achievement. Later, as China's urbanization advanced, Shen (2018) proposed that principal leadership should include situation-adaptive ability in response to the challenges of the expanded school size and teaching force brought on by urbanization. Likewise, Zhao (2009) first introduced into the Chinese education community Sergiovanni's (1984) principal leadership framework, which highlighted five aspects of leadership: technical, human, educational, symbolic, and cultural. When the Chinese government released the national developmental strategy of rural revitalization, Yang et al. (2023) worked to adapt this theoretical framework to the actual circumstances of Chinese rural schools by rephrasing the five leadership forces as cultural leadership that integrates leadership into rural cultural revitalization; symbolic leadership that responds to rural revitalization advocacy; educational leadership that demonstrates professional support; human leadership that harnesses home-school co-education resources; and technical leadership that strives for the retention of rural teachers.

As a result of the advances in information technology and the implications of the COVID-19 pandemic for educational organizations, researchers across the globe have realized the significance of digital leadership and the use of digital technologies for the improvement of school management (Neyişci & SARI, 2023; Gao et al., 2024; Zhao et al., 2024). Berkovich and Hassan (2023) investigated the impact of digital transformational leadership on school management outcomes in Bahraini schools. Deploying digital communication and collaboration tools to support teachers' remote instruction was a paramount indicator of the digital transformation leadership of the principal in their evaluation. According to Zhou et al. (2023), to adapt to the new ecology of smart education built on technologies such as human-machine collaboration, primary and secondary principals must hold a growth mindset and continuously develop crucial capabilities such as intelligent technology literacy, ethical judgment on intelligent education, digital communication, and intelligent education foresight. In addition, some studies have rated agility as an important quality of principal leadership in the new era (Buffone, 2021). In the meantime, new leadership models have been established in reaction to emerging education modalities. For example, Geiger et al. (2023) proposed a principal leadership model for STEM education, which evaluates the principal's leadership in supporting STEM education in multiple dimensions, including interdisciplinary knowledge and practice, STEM intention, the adoption of instruments, and more.

In summary, the new-generation principal leadership exhibits fresh qualities as the result of the incorporation of new factors as well as the modification of prior elements. Also, some decades-old principal leadership models remain in use among current researchers, such as the multifactor leadership model developed by Bass and Avolio (1997), which has implications for the development of principal leadership in the Singaporean educational context (Wang et al., 2023).

Essential Qualities of Primary and Secondary Principal Leadership

Principal leadership is a multifaceted and complicated construct. Some researchers may describe it as the ability to influence (Ying, 2009), a capacity of the principal to motivate school members with their visions and supportive behavior and to make best use of resources, laying a solid foundation for further changes (Higgs & Rowland, 2000; Ahmad et al., 2023). Some may argue that principal leadership is an integration process (Rayner, 2009), in which the principal integrates the forces of teachers, students, and other stakeholders (Daniëls, 2019). However, the majority of them defined principal leadership as a combination of core abilities a principal must possess to play the role of a school leader (Sun, 2012; Musthan, 2019; Liu, 2023) and to achieve school development goals in collaboration with people under their leadership (Zhang, 2007). In this study, we seek to summarize the essential qualities of principal leadership in the dimensions of personal traits, the capacity to influence people, and the ability to make ongoing organizational improvements on the basis of our analysis of existing literature.

Among the personal traits related to educational leadership, excellent communication skills, agility, and an open mindset are the most crucial for the principal's fulfillment of their leadership roles. First, the importance of effective communication skills for principal leadership has been highly emphasized in existing research (e.g., Dai & Wan, 2011; Xu, 2012; Da'as, 2016; Ahmad et al., 2023). Aside from maintaining effective communication with school members, the principal also has the responsibility to establish smooth communication channels with external individuals or organizations. Inefficient or ineffective communication is detrimental to interpersonal relationships both inside and outside the school (Daniëls et al., 2019), which has a negative impact on its management outcomes. Therefore, skillful communication is an integral part of principal leadership. Second, agility (Buffone, 2021) is a relatively newly advanced concept in principal leadership research, encompassing a variety of leadership elements such as insightful evaluation of the time (Cao, 2023), contextual intelligence (Noman et al., 2018; Shen, 2018; Yusof & Ariffin, 2023), and foresight (Dou, 2007; Wang, 2011; Musthan, 2019). Agile school leaders can not only accurately identify the development needs of the school but also successfully perceive the opportunities and challenges brought by shifts in the external educational landscape to the school's development. To be agile, the principal must be alert to imminent changes in education while also being perceptive to the current operational state of the school, including its strengths and weaknesses. Third, having an open mindset ensures that the principal can continuously increase their level of professionalism (Zhang, 2023). A lifelong-learning attitude and awareness of constantly updating educational concepts can help them avoid professional stagnation (Zhang, 2023) and embrace new requirements for principal leadership in the digital era (Cao, 2023).

In the dimension of the capacity to influence people, a successful principal is distinguished by their commitments to improving instructional quality, assisting teacher professional development, and serving as a role model for school members. First off, there is a consensus among researchers (e.g., Zhang et al., 2014; Antoniou & Lu, 2018; Aldighrir, 2024) that, as a school manager, the principal must focus on improving the quality of teaching and meeting students' diverse needs for learning, since teaching and learning are the two chief activities in a school setting. Second, the principal should also pay attention to the building of a potent teaching force and the professional development of teachers (e.g., Zhang, 2007; Hu, 2022; Zeinabadi, 2023). Recommendations for the principal in this regard include providing ample training opportunities for teachers to increase their professional expertise and competences (e.g. Shen & Sun, 2014; Cheng & Zhang, 2023); setting goals for teacher performance (Leithwood, 2005) and giving them timely feedback and rewards (Daniëls et al., 2019); striking a balance between regulating educational behavior and motivating instructional innovation in teachers (Li et al., 2012); reaching out with empathy and concern to the staff (Guo, 2022; Kramer, 2023) and guiding them to nuture positive emotions, attitudes, and values for their jobs (Li et al., 2012). Third, researchers agreed that the best way for the principal to influence their staff is to be a good role model for them (Gkolia et al., 2021; Liu, 2023), particularly in professional advancement (Xu, 2012).

Additionally, to advance the overall development of the school, the principal should have the ability to set shared development visions and goals for the school, create positive and inclusive educational atmospheres, and manage the school in collaboration with the staff. First, explicitly defining the development vision and mission of the school on the part of the school leader is generally rated as an effective means for enhancing the school's management efficiency in prior studies (e.g., Ying, 2009; Norman, 2016; Emmanuel & Valle, 2021; Guo, 2022). Second, the principal can unite the staff members to make joint efforts to advance the development of the school by creating a positive and inclusive school climate (Hallinger & Murphy, 1985; Yusof & Ariffin, 2023), for which respect for individual differences, trust between school members, and a healthy campus culture are the most vital factors (Leithwood, 2005; Zeinabadi, 2023). Third, teamwork awareness and coordination ability of the principal are regarded as fundamental to ensuring highly efficient school operation and optimal school resource utilization in the literature (Xu, 2012; Cheng & Zhang, 2023).

Conclusion

Based on relevant literature on principal leadership, our survey seeks to identify crucial components of principal leadership at the basic education level while also looking into the variations in its definition between Chinese and overseas researchers. Research results show that these variations are attributable to plural factors, including educational reform, education policy adjustment, and cultural diversity, as well as specific theoretical underpinnings.

We suggest that when looking at different principal leadership theories and models, researchers should focus more on spotting commonalities among them than on judging which of them are superior or inferior.

After analyzing 60 journal articles on principal leadership published globally, we extracted the essential qualities of principal leadership as follows: excellent communication skills, agility, and an open mind set in the dimension of personal character; focusing on the instructional quality, being supportive of teacher professional development, and acting as a role model for school members in the dimension of the capacity to influence people; establishing shared developmental visions for the school; creating a positive and inclusive educational climate; and managing the school in collaboration with the staff in the dimension of driving the ongoing development of the school. These key elements reflect the basic understanding of the roles of primary and secondary principals among global researchers at different times. A thorough discussion of these elements is beneficial for designing legitimate principal training programs, heightening the leadership capacity of primary and secondary principals, and consequently, advancing the development of basic education across the board.

It should be acknowledged that this survey has its limitations. Constrained by the scope of databases used, search keywords, and screening criteria, the review may not be sufficiently exhaustive to cover all significant research on the leadership of basic education school principals. Nonetheless, it can still serve as a steppingstone to further research on the interactions between the said essential leadership qualities and their potential impacts on instruction, as well as future explorations of practical issues such as the development of principal leadership assessment scales and the formulation of principal leadership education and training programs.

References

(The Studies included in the literature review are marked with asterisks)

Ahmad, M. S. bin, Ahmad, R., & Ramli, F. Z. A. (2023). Needs Analysis Review: Constructs of Integrated Principal Leadership Model and Counselling Approach. Available at: http://www.gjat.my/gjat2023-Jul/5.pdf

*Ai, X. & Zhao, R. (2019). Integrating traditional Chinese educational management culture into principal leadership. *Journal of Teaching and Management*, 2019(15):42-45.

*Aldighrir, W. M. (2024). Psychometric Properties of the Principal Instructional Leadership Scale (PILS) in Saudi Arabia. *Acta Psychologica*, 246:104262. DOI: https://doi.org/10.1016/j.actpsy.2024.104262

*Antoniou, P., & Lu, M. (2018). Evaluating the measuring properties of the principal instructional management rating scale in the

Chinese educational system: Implications for measuring school leadership. *Educational Management Administration & Leadership*, 46(4):624-641. DOI: http://doi.org/10.1177/1741143217700282

*Arar, K., Sawalhi, R., & Yilmaz, M. (2022). The research on Islamic-based educational leadership since 1990: An international review of empirical evidence and a future research agenda. *Religions*, 13(1):42. https://doi.org/10.3390/rel13010042

Bass, B. M. & Avolio, B. J. (1997). Full Range Leadership Development: Manual for the Multifactor Leadership Questionnaire. Palo Alto, CA.: Mind Garden.

*Bass, B. M., Avolio, B. J., Jung, D. I., & Berson, Y. (2003). Predicting unit performance by assessing transformational and transactional leadership. *Journal of Applied Psychology*, 88(2):207-218. DOI: https://doi.org/10.1037/0021-9010.88.2.207

*Berkovich, I. & Hassan, T. (2023). Principals' digital transformational leadership, teachers' commitment, and school effectiveness. *Education Inquiry*, 2023:1-18. DOI: https://doi.org/10.1080/20004508.2023.2173705

*Buffone, P. (2021). Agility: An essential element of leadership for an evolving educational landscape. *Facets*, 6(1):1610-1620. DOI: http://doi.org/10.1139/facets-2021-0085

*Cao, P. (2023). Restructuring principal leadership in the context of the digital transformation of education. *School Administration*, 2023(1):9-12.

*Chen, D. & Yang, X. (2020). Features of outstanding principals in the United States: An analysis based on data of winners of "Terrel Howard Bell Leadership Award of the Year 2018." *International and Comparative Education*, 2020(3):59-65+82.

*Cheng, X. & Zhang, S. (2023). Principal leadership improvement under the Double Reduction Policy. *Hubei Social Sciences*, 2023(3):149-154. DOI: https://doi.org/10.13660/j.cnki.42-1112/c.016063

*Da'as, R. A. (2017). School principals' leadership skills: Measurement equivalence across cultures. Compare: A Journal of Comparative and International Education, 47(2):207-222. DOI: http://doi.org/10.1080/03057925.2016.1210504

*Dai, R. & Wan, H. (2011). The role of principal leadership in teachers' career development. *Teacher Education Research*, 23(5):27-31. DOI: https://doi.org/10.13445/j.cnki.te.r.2011.05.004

*Daniëls, E., Hondeghem, A., & Dochy, F. (2019). A review on leadership and leadership development in educational settings. *Educational Research Review*, 27(3):110-125. DOI: http://doi.org/10.1016/j.edurev.2019.02.003

*Dou, G. (2007). Crucial leadership skills for modern principals. *Journal of the Chinese Society of Education*, 2007(9):48-50.

*Emmanuel, S., & Valley, C. A. (2022). A qualitative case study of exemplary principal leadership in the United States Virgin Islands: an application of Kouzes and Posner's five practices of exemplary leadership. *Journal of Research on Leadership Education*, 17(3):243-264. DOI: https://doi.org/10.1177/19427751219900054

*Geiger, V., Beswick, K., Fraser, S., & Holland-Twining, B. (2023). A model for principals' STEM leadership capability. *British Educational Research Journal*, 49(5):900-924. DOI: https://doi.org/10.1002/berj.3873

*Gkolia, A., Tsigilis, N., Evangelou, M., & Koustelios, A. (2022). Factorial Validity and Measurement Invariance of the Principal Leadership Questionnaire in Greek Educational Context. *Psychological Reports*, 125(4):2292-2311. DOI: https://doi.org/10.1177/00332941211009130

*Goldring, E., Cravens, X. C., Murphy, J., Porter, A. C., Elliott, S. N., & Carson, B. (2009). The evaluation of principals: What and how do states and urban districts assess leadership? *The Elementary School Journal*, 110(1):19-39. DOI: http://doi.org/10.1086/598841

*Grissom, J. A., & Loeb, S. (2011). Triangulating Principal Effectiveness: How Perspectives of Parents, Teachers, and Assistant Principals Identify the Central Importance of Managerial Skills. *American Educational Research Journal*, 48(5):1091-1123. DOI: https://doi.org/10.3102/0002831211402663

*Guo, X. (2022). The four chief dimensions of principal leadership. *Theory and Practice of Education*, 2022(14):20-22.

Hallinger, P., Gümüş, S., & Bellibaş, M. Ş.

(2020). 'Are principals instructional leaders yet?' A science map of the knowledge base on instructional leadership, 1940-2018. *Scientometrics*, 122(3):1629-1650. DOI: http://doi.org/10.1007/s11192-020-03360-5

*Hallinger, P., & Murphy, J. (1985). Assessing the instructional management behavior of principals. *The Elementary School Journal*, 86(2):217-247. DOI: http://doi.org/10.1086/461445

He, P., Guo, F., & Abazie, G. A. (2024). School principals' instructional leadership as a predictor of teacher's professional development. *Asian-Pacific Journal of Second and Foreign Language Education*, 9(1):63. DOI: https://doi.org/10.1186/s40862-024-00290-0

*Higgs, M. and Rowland, D. (2000). Building Change Leadership Capability: The Quest for Change Competence. *Journal of Change Management*, 1(2):116-130. DOI: http://doi.org/10.1080/714042459

*Hu, T. (2022). Leadership models and characteristics of successful principals: Using ISSPP as an example. *Studies in Foreign Education*, 2022(9):64-83.

Karadağ, E., Bektaş, F., Çoğaltay, N., & Yalçın, M. (2015). The effect of educational leadership on students' achievement: A meta-analysis study. *Asia Pacific Education Review*, 16(1):79-93. DOI: http://doi.org/10.1007/s12564-015-9357-x

*Kharbat, N. F. & AlSoud, R. (2019). The engage model: A proposed educational administrative model of change leadership for school leaders. *Global Journal Al-Thaqafah*, 9(1):7-22.

*Kramer, M. (2023). More than a principal: Ubuntu at the heart of successful school leadership in the Western Cape. *South African Journal of Education*, 43(3):1-10. DOI: http://doi.org/10.15700/saje.v43n3a2168

*Kutz, M. R. (2008). Toward a conceptual model of contextual intelligence: A transferable leadership construct. *Leadership Review*, 8(2):18-31.

*Lai, H.-C., & Lien, H.-Y. (2023). Instructional leadership scale for high school principals: Development and validation. *Educational Management Administration & Leadership*, 0(0). DOI: https://doi.org/10.1177/17411432231177531

*Leithwood, K. (1994). Leadership for school restructuring. *Educational Administration Quarterly*, 30(4):498-518. DOI: https://doi.org/10.1177/0013161X94030004006

*Leithwood, K. (2005). Understanding successful principal leadership: Progress on a broken front. *Journal of Educational Administration*, 43(6):619-629. DOI: http://doi.org/10.1108/09578230510625719

*Leithwood, K. & Jantzi, D. (2000). The effects of transformational leadership on organizational conditions and student engagement with school. *Journal of Educational Administration*, 38(2):112-129. DOI: https://doi.org/10.1108/09578230010320064.

*Leithwood, K., Harris, A., & Hopkins, D. (2020). Seven strong claims about successful school leadership revisited. *School Leadership & Management*, 28(1):1-18. DOI: https://doi.org/10.1080/13632430701800060

*Li, X., Li, W., & Lu, N. (2012). Principal leadership effective in promoting teacher development: A case study of two junior secondary principals. *Research in Educational Development*, 2012(4):70-74. DOI: https://doi.org/10.14121/j.cnki.1008-3855.2012.04.017

*Liu, L. (2023). Enhancing principal leadership in the new era: Significance and Paths. *School Administration*, 2023(3):13-16.

*Liu, Y. (2023). Being a role model, guidance, and concern: Three essential elements of principal leadership in the new era. *School Administration*, 2023(3):21-24.

*Mohd Yusoff, S., & Tengku Ariffin, T. F. (2023). Development and validation of contextual leadership instrument for principals in Malaysian school context (MyCLIPS). *Leadership and Policy in Schools*, 22(2):402-417. DOI: http://doi.org/10.1080/15700763.2021.1971259

Mumford, T. V., Campion, M. A., & Morgeson, F. P. (2007). The leadership skills strataplex: Leadership skill requirements across organizational levels. *The Leadership Quarterly*, 18(2):154-166. DOI: https://doi.org/10.1016/j.leaqua.2007.01.005

*Musthan, Z. (2019). An Effective Leadership Model for Madrasah Principals in Indonesia. Pertanika *Journal of Social Sciences & Humanities*, 27(1):133-147.

*Neyişci, N. İ. L. A. Y., & SARI, B. (2023). Digital Leadership in Educational Institutions during the COVID-19 Pandemic. *Hacettepe Üniversitesi Eğitim Fakültesi Dergisi*, 38(4):516-523. DOI: http://doi.org/10.16986/huje.2022.463

*Noman, M., Awang Hashim, R., & Shaik Abdullah, S. (2017). Principal's coalition building and personal traits brings success to a struggling school in Malaysia. *Qualitative Report*, 22(10):2652-2672. DOI: https://doi.org/10.46743/2160-3715/2017.2748

*Noman, M., Awang Hashim, R., & Shaik Abdullah, S. (2018). Contextual leadership practices: The case of a successful school principal in Malaysia. *Educational Management Administration & Leadership*, 46(3):474-490. DOI: https://doi.org/10.1177/1741143216665840

*Rayner, S. (2009). Educational diversity and learning leadership: A proposition, some principles and a model of inclusive leadership. *Educational Review*, 61(4):433-447. DOI: https://doi.org/10.1080/00131910903404004

*Sergiovanni, T. (1984). Leadership and excellence in schooling. *Educational Leadership*, 41(5):4-13.

*Shen, W. (2018). Principal leadership in the context of urbanization: A study based on spatial sociology. *Research in Educational Development*, 38(18):45-52. DOI: https://doi.org/10.14121/j.cnki.1008-3855.2018.18.009

*Shen, W. & Sun, Y. (2014). Principal leadership in the context of educational accountability: Connotations, a structural framework, and development. *Teacher Education Research*, 2014(05):81-87. DOI: https://doi.org/10.13445/j.cnki.te.r.2014.05.014

*Sun, M. (2012). Basic elements of principal leadership. *Educational Research and Experiment*, 2012(6):54-57.

*Veletić, J., Price, H. E., & Olsen, R. V. (2023). Teachers' and principals' perceptions of school climate: the role of principals' leadership style in organizational quality. *Educational Assessment, Evaluation and Accountability*, 35(4):525-555. DOI: https://doi.org/10.1007/s11092-023-09413-6

Walker, A. & Hallinger, P. (2015). A synthesis of reviews of research on principal leadership in East Asia. *Journal of Educational Administration*, 53(4):554-570. https://doi.org/10.1108/JEA-05-2015-0038

*Wang, J. C. K., Liu, W. C., Kee, Y. H., Ng, B., Chua, L., & Hu, L. (2023). Measuring educational leadership in Singapore: re-examining the psychometric properties of the Multifactor Leadership Questionnaire. *Frontiers in Psychology*, 14:1280038. https://doi.org/10.3389/fpsyg.2023.1280038

Wang, X. (2015). A survey of principal leadership styles in Western teacher professional learning communities. *Modern Education Management*, 2015(10):103-108. DOI: https://doi.org/10.16697/j.cnki.xdjygl.2015.10.018

*Wang, Y. (2011). Enhancing the leadership of primary and secondary principals. *Fujian Forum (Humanities and Social Sciences Edition)*, 2011(S1):139-140.

*Xu, J. (2012). Professional development and leadership building of Australian primary and secondary principals. *Academic Exploration*, 2012(2):163-166.

*Xu, J. & Zhu, Y. (2019). Professional preparation and development of future principals: Findings and implications based on TALIS 2018 Shanghai data. *Global Education*, 48(9):101-113. DOI: https://doi.org/10.3969/j.issn.1009-9670.2019.09.009

Yan, W. (2022). A review of Western principal leadership: Theory, model, and implications. *Journal of National Academy of Education Administration*, 2022(4):78-87.

*Yang, X., Zhang, Y., & Li, X. (2023). Leadership of rural small-scale school principals. *School Administration*, 2023(8):44-48.

*Ying, P. (2009). The role of principal leadership in school development: With a discussion on misconceptions of principal leadership. *Educational Science Research*, 2009(12):28-31.

*Zeinabadi, H. (2023). Breaking down the walls of weak knowledge-sharing among Iranian teachers: Investigating a less-considered leadership role of principals. *Educational Management Administration & Leadership*, 51(1):176-197.

*Zhang, L. (2013). Exploration of issues with primary and secondary principal leadership from the perspective of professionalism. *Journal of the Chinese Society of Education*, 2013(6):45-48.

*Zhang, S. (2007). Principal leadership: Background, connotations, and practices. *Journal of the Chinese Society of Educa-*

tion, 2007(9):42-47+54.

*Zhang, S. (2009). Principal leadership from the perspective of complexity science. *Journal of the Chinese Society of Education*, 2009(10):26-29.

*Zhang, X. (2023). Reflections on principal leadership in the era of change. *School Administration*, 2023(3):9-12.

*Zhang, X., Tong, L., & Xia, G. (2014). Leadership evaluation methods for Australian primary and secondary principals. *Studies in Foreign Education*, 2014(12):77-87.

*Zhao, D. & Zhou, Y. (2017). Leadership of Chinese principals: An analysis based on data from PISA2015 questionnaire survey of principals from four provincial administrative regions of China. *School Administration*, 2017(10):5-8.

*Zhao, D., Zhou, Z. & Luo, N. (2014). What kind of principal leadership is needed for the high-quality development of education. *School Administration*, 2014(1):9-13.

*Zhao, M. (2009). On principal leadership. *Educational Science Research*, 2009(1):40-42. DOI: https://doi.org/10.3969/j.issn.1009-718X.2009.01.009

Zheng, Q., Li, L., Chen, H., & Loeb, S. (2017). What Aspects of Principal Leadership Are Most Highly Correlated with School Outcomes in China? *Educational Administration Quarterly*, 53(3):409-447. DOI: https://doi.org/10.1177/0013161X17706152

*Zhou, Q., Kang, X., Zhang, L., & Liang, K. (2023). Leadership of contemporary Chinese primary and secondary principals. *China Educational Technology*, 2023(6):75-82.

Received: June 14, 2024
Revised: July 01, 2024
Accepted: July 17, 2024

Science Insights Education Frontiers
pISSN 2644-058X eISSN 2578-9813

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Vol. 23, No. 2, 2024

pISSN: 2644-058X
eISSN: 2578-9813
DOI: 10.15354/sief