ASCILITE 2024
Navigating the Terrain:
Emerging Frontiers in Learning Spaces, Pedagogies, and Technologies

The Funnel Transformative Model of Science Education: An Innovative Approach Awaiting Validation

Jorge Reyna
The Royal Australian and New Zealand College of Ophthalmologists (RANZCO), Sydney, Australia

Marta Romero Ariza, Antonio Quesada Armenteros
University of Jaén, Jaén, Spain

This theoretical paper proposes a model to address the multifaceted challenges of science education by integrating two evidence-based approaches: the Learner-Generated Digital Media (LGDM) projects framework and the Cognitive Acceleration through Science Education (CASE) framework. The Model is analogous to a funnel, with its wide top representing the broad field of science education and its narrow bottom symbolising transformative learning. It leverages LGDM's self-regulation benefits and CASE's structured five-stage approach – Concrete Preparation, Cognitive Conflict, Social Construction, Metacognition, and Bridging. The model categorises the complexity of science learning into six critical pillars: lack of conceptual understanding, cognitive challenges, language barriers, lack of hands-on learning, lack of robust assessments, and social issues. Applying the Funnel Model aims to develop cognitive skills, enhance learning strategies, and foster practical skills. This paper presents the Funnel Model and discusses a methodological approach to validation using Design-Based Research (DBR). The research plans to address three key questions to refine and enhance the Funnel Model in improving science education outcomes.

Keywords: Science Education, Cognitive Acceleration, Digital Media, Design-Based Research.

Introduction

Science education faces significant challenges, including student misconceptions, cognitive overload, abstract reasoning difficulties, language barriers, and social issues (Chen & Xiao, 2021; Kaptan & Timurlenk, 2012; McGee, 2021; Thomas & Boon, 2023). Traditional methods, such as rote learning and teacher-directed instruction, often fail to engage students meaningfully, leading to poor retention and understanding (Roth, 2013). The Funnel Transformative Model of Science Education aims to address these issues by integrating two powerful evidence-based instructional strategies: Learner-Generated Digital Media (LGDM) projects (Reyna et al., 2016) and the Cognitive Acceleration through Science Education (CASE) framework (Adey & Shayer, 2015). This model promotes deeper understanding and lasting engagement by combining the practical benefits of digital media projects with the structured stages of CASE.

LGDM involves students creating digital media content, such as videos, animations, infographics, 3D models, and VR content, to explore and explain scientific concepts (Reyna & Meier, 2018). This approach fosters active learning, self-regulation, higher-order thinking, and research skills while encouraging creativity, collaboration, and communication in the digital space (Reyna & Meier, 2018; Reyna et al., 2017). LGDM also addresses group dynamics, ensuring all members contribute to a project using a groupwork marking rubric (Reyna, 2020). CASE, on the other hand, develops students' cognitive abilities through five stages: Concrete Preparation, Cognitive Conflict, Social Construction, Metacognition, and Bridging (Adey & Shayer, 2015). This structured approach promotes critical thinking, deeper understanding, and the ability to apply knowledge to novel situations, making education more relevant and applicable to students' lives (Shayer, 1999).

Integrating LGDM with the CASE framework creates a powerful synergy that addresses the multifaceted challenges of science education. The Funnel Model is intended to be flexible and can be effectively applied across various educational levels, including early childhood, primary, secondary, undergraduate, and postgraduate education. This research aims to present the Funnel Transformative Model of Science Education for future validation, addressing the need for a comprehensive model for digital science education and discussing its potential and methodological approach for refinement.

Instructional approaches to science learning

Science education has undergone significant transformations over the decades, with various instructional models developed and implemented to enhance learning outcomes (Hmelo-Silver, 2006; Hushman & Marley, 2015). The complexity and abstract nature of scientific concepts often pose challenges for students and educators, requiring innovative approaches to teaching. This section examines current instructional approaches to science learning that try to address these challenges, their sequence reflecting a logical progression from broad, flexible frameworks to more structured, detailed methods. This ensures a comprehensive understanding of the benefits and drawbacks of these diverse instructional strategies in science education.

Project-based learning (PjBL)

Project-Based Learning (PjBL) is an instructional methodology that encourages students to learn and apply knowledge through engaging projects around real-world problems and challenges. Unlike traditional instruction where the teacher directs learning, PjBL places students in a more active role where they must investigate and respond to complex questions or tasks (Nurhidayah et al., 2021). This method is claimed to promote deeper learning and is intended to help students develop critical thinking, collaboration, and communication skills. Research has shown that PjBL can increase student motivation and engagement by making learning relevant and meaningful (Diana & Sukma, 2021).

One significant challenge of PjBL is the need for substantial time and resources to design and implement practical projects, which can put strain on teachers and school budgets (Aksela & Haatainen, 2019). Not all educators have the training or experience necessary to facilitate PjBL effectively, potentially leading to uneven student experiences and outcomes (Ferwati et al., 2023). The open-ended nature of PjBL can also be daunting for some students, particularly those who need help with self-directed learning or managing complex tasks. Furthermore, assessing student performance in PjBL can be challenging because traditional assessment methods may not capture the full range of skills and knowledge developed in projects (Nurhidayah et al., 2021). Finally, PjBL's focus on specific projects may limit the breadth of content coverage, potentially leaving gaps in students' overall understanding of the subject matter (Mihic & Zavrski, 2017).

Problem-based learning (PBL)

This approach is a student-centred pedagogy that involves learning about a subject by solving an open-ended problem. Grounded in constructivist principles, PBL aims to develop critical thinking, problem-solving skills, and self-directed learning (Hmelo-Silver, 2004). In PBL, students typically work in small groups to tackle real-world problems, guided by a facilitator rather than a traditional instructor. This method can encourage deep learning and the application of knowledge to novel situations (Hmelo-Silver, 2006). Studies have shown that PBL can enhance student motivation and engagement with science learning, making it a valuable approach which fosters lifelong learning skills (Savery, 2015).

One major challenge of Problem-Based Learning (PBL) is the high demand it places on teachers, who need to skilfully guide discussions, prompt critical thinking, and manage group dynamics without directly providing answers, which can be difficult for those used to traditional teaching methods (Hmelo-Silver, 2006). Additionally, PBL can be time-consuming, requiring significant preparation to develop and implement complex real-world problems that align with curriculum standards. The open-ended nature of problems complicates assessment and can result in variable learning outcomes (Savery, 2015). Furthermore, groupwork dynamics can lead to unequal participation, with some students dominating and others becoming passive, which creates challenges for a collaborative and inclusive learning environment.

Inquiry-based learning (IBL)

This model emphasises the importance of students actively engaging in the scientific process by asking questions, designing experiments, collecting and analysing data, and proposing evidence-based conclusions. Inquiry-based learning (IBL) can be implemented at varying guidance levels, from structured inquiry with teacher-provided questions through to open inquiry, where students create their own research questions and methods. Research has shown that IBLs may be effective in enhancing students' understanding of scientific concepts and processes, fostering a deeper appreciation of science and its methodologies (Aparicio-Ting et al., 2019).

However, IBL could also place significant demands on both students and teachers (Hinostroza et al., 2024). Students need high levels of self-direction and motivation, which can be challenging for those used to traditional instruction (Kaçar et al., 2021). They may struggle to formulate research questions and design experiments, especially without prior experience or foundational knowledge (Minner et al., 2010). Teachers must facilitate inquiry without providing too much direction, a balance which can be difficult to strike as insufficient guidance can frustrate students, while too much can limit independent learning (Seneviratne et al., 2019). Additionally, the open-ended nature of IBL can complicate assessment because traditional tests may not capture the depth of inquiry skills and understanding, thus requiring educators to develop creative assessment strategies (Hinostroza et al., 2024).

STEM education

This model integrates science, technology, engineering, and mathematics education into a robust learning paradigm based on real-world applications. This interdisciplinary approach aims to equip students with the skills necessary for the 21st century, emphasising critical thinking, creativity, and problem-solving (Ortiz-Revilla et al., 2022). STEM initiatives often involve project-based learning, where students undertake complex tasks that require integrating knowledge from multiple disciplines. Studies have shown that STEM education can enhance students' interest and achievement in science and related fields, preparing them for future careers (Wei & Chen, 2020).

The STEM education model faces several limitations, such as unequal access to resources and specialised equipment, which can lead to disparities in educational opportunities, particularly in underfunded or rural areas (Nepeina et al., 2020). The time-consuming nature of project-based learning can present challenges in balancing curricular requirements and managing long-term projects. Furthermore, traditional assessment methods (e.g. MCQs) often fail to capture the full range of skills developed through STEM activities (Kelley & Knowles, 2016).

Flipped classroom model

The Flipped Classroom Model reverses traditional learning by delivering instructional content online outside the classroom, while in-class time is used for interactive activities that foster problem-solving (Bergmann & Sams, 2012). This approach allows students to learn at their own pace and increases opportunities for active learning, peer collaboration, and teacher support, thereby improving student engagement and achievement (Jdaitawi, 2019). However, the model faces several challenges, including ensuring equitable access to the necessary technology, relying on students' self-motivation and time management skills, and the substantial effort required from teachers to create quality instructional videos and redesign class activities (Reyna, 2019b).

The 5E instructional model

This model was developed by the Biological Sciences Curriculum Study (BSCS) (Bybee et al., 2006) and is one of science education's most widely used frameworks. It comprises five phases: Engage, Explore, Explain, Elaborate, and Evaluate (Joswick & Hulings, 2024). This model is designed to facilitate conceptual understanding and foster scientific inquiry. Engage captures students' interest and elicits prior knowledge.

Explore provides hands-on experiences where students investigate scientific concepts. Explain encourages students to articulate their understanding and enables teachers to provide explanations. Elaborate extends students' knowledge through new experiences and applications. Finally, Evaluate assesses students' understanding and skills (Koyunlu Ünlü & Dökme, 2022). Research indicates that the 5E Model promotes active learning and helps students better understand scientific concepts, making it a powerful tool for science educators (Garcia I Grau et al., 2021).

The 5E Instructional Model has several limitations. Its effectiveness depends heavily on teachers' experience and expertise, which can vary significantly (Balci et al., 2006). The model may only partially address the diverse needs of some students, especially those requiring individualised instruction or additional support (Boddy et al., 2003). Additionally, the resource-intensive nature of hands-on exploration can challenge schools with limited access to materials and equipment (Bybee et al., 2006). The model's emphasis on inquiry-based learning may need to align better with standardised testing practices prioritising rote memorisation. Lastly, integration of technology into the 5E framework can be inconsistent, as some educators need help with incorporating digital tools into their lessons effectively (Kim & Reeves, 2007).

Drawbacks of traditional science instructional approaches

Traditional science instructional approaches face several challenges, including the substantial time and resources required for practical projects and extensive teacher preparation and training. Many educators need more experience to manage group dynamics and facilitate effective learning with direct instruction, leading to uneven implementation and varying student outcomes. Student engagement and self-regulation are critical, as students may struggle with self-directed tasks and groupwork dynamics, resulting in unequal participation. Assessment methods often fail to capture the full range of skills developed through project-based learning, and logistical constraints make it difficult to manage long-term projects within limited classroom time. Additionally, these models do not adequately address misconceptions, cognitive overload, language barriers, or the abstract nature of scientific principles. Limited access to hands-on learning exacerbates educational inequalities, and practical assessment methodologies are crucial for aligning evaluations with learning objectives. Integrating social issues into science education is essential for fostering an inclusive environment, addressing disparities among gender, minority, and marginalized groups, and creating a diverse and inclusive STEM workforce.

The proposed approach: the Funnel Transformative Model of science education

In science education, analogies are powerful tools often used to explain complex concepts by drawing familiar comparisons (Coll et al., 2005). Traditionally underused for proposing instructional models, analogies can also help educators simplify and systematise the complexity of science education (Glynn, 2015). For instance, the classroom could be envisioned as a funnel guiding students through a transformative learning journey using the LGDM-CASE approaches. At the mouth of the funnel, students would encounter various digital media literacy frameworks and scientific concepts. As they investigate more deeply, the funnel narrows, symbolising the increasing focus and depth of their learning experiences. Through hands-on engagement with LGDM-CASE activities, students would undergo cognitive development, face cognitive conflict, develop social constructs, and engage in metacognitive reflection. They would grapple with challenges, collaborate with peers, and reflect on their learning processes while integrating scientific content with digital media creation. Ultimately, at the funnel's end, students would emerge transformed, equipped with a deep understanding of scientific concepts, the ability to apply their knowledge in real-world contexts, and enhanced digital media literacy skills. Thus, the integration of LGDM-CASE could foster a transformative learning experience, guiding students through discovery, collaboration, and growth in the classroom. Figure 1 represents this proposed model.

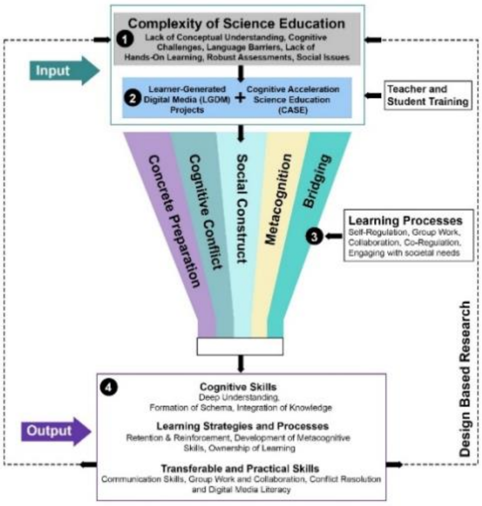

Figure 1. The Funnel Transformative Model of Science Education

The complexity of science education (1)

This section of the Funnel Model (1) represents the multifaceted challenges encountered by science students, outlining obstacles that can hinder their progress and comprehension. It emphasises the foundational importance of conceptual clarity which overcomes entrenched misconceptions that impede science learning. Some examples include preconceived notions, non-scientific beliefs, conceptual misunderstandings, and language or vocabulary misunderstandings. Also, contextual voids and the abstract nature of scientific principles can negatively impact science learning (Suprapto, 2020). Moreover, the model investigates students' cognitive challenges, including the often overwhelming burden of assimilating vast amounts of information, as well as the complex abstract reasoning needed to understand scientific theories. (Meissner & Bogner, 2013). Language barriers can further compound these challenges, particularly with translating technical jargon and articulating scientific ideas effectively (Amano et al., 2021). It helps students understand science better if they learn by doing things themselves, but there are barriers that prevent students from getting valuable hands-on experience (Lombardi et al., 2021). This section of the model also emphasises robust assessment methodologies to gauge students' grasp of scientific knowledge, assessments that align with learning objectives and are authentic, reliable, and conducive to metacognitive growth. It also reflects the importance of integrating social issues into science education. It highlights the significance of recognising and addressing disparities regarding gender (Harding, 2023) and minority or marginalised groups like Indigenous (Mizetti et al., 2020) and LGBT+ students (Reggiani et al., 2024) to foster an inclusive and empathic learning environment.

Learner-Generated Digital Media (LGDM) projects (2)

LGDM (Learner-Generated Digital Media) integrates various frameworks to enhance digital media literacy and optimise digital media projects in science education. It uses a blended learning approach to train students and educators in digital media production and incorporates the three domains of digital media literacy from the Digital Media Literacies Framework (Reyna et al., 2018a) – Conceptual (storyboard), Functional (software), and Audio-visual (digital media principles). The application of this framework has been shown to help educators and students develop the skills needed to create compelling digital media projects, with marking rubrics to assess proficiency also based on these domains. The Taxonomy of Digital Media Types (Reyna et al., 2017) can help with designing digital media projects by giving students an understanding of the complexity and variety of digital artefacts. This guides task design, task weighting, and group dynamics, educating teachers and students alike about the production process and required skills. Additionally, LGDM integrates principles like layout design, colour theory, typography, and basic video techniques from the Digital Media Principles (Reyna et al., 2018b) into teacher and student training, which could assist the creation of high-quality LGDM projects that effectively convey messages. The Digital Media Project Implementation Framework (Reyna & Meier, 2018) can also provide a comprehensive understanding of the flow of digital media projects, including pedagogy, student training, feedback, and evaluation, addressing the ‘Why, What, and How’ of implementation to facilitate effective communication between teachers and students.

Cognitive Acceleration through Science Education (CASE) model (2)

The Cognitive Acceleration through Science Education (CASE) Model provides a structured approach to fostering cognitive development in science education (Adey & Shayer, 2015), which synergises effectively with LGDM projects. Several studies have investigated the impact of CASE on student learning across various disciplines (Hugerat et al., 2014; Oliver & Venville, 2015; McCormack et al., 2014; Sarwar & Muhammad, 2021). In mathematics education, CASE demonstrated increased teacher efficacy, enhanced teaching practices, and student gains positively impacting teacher confidence and classroom dynamics (Seleznyov et al., 2022). In physics education in fourth-grade students, a study demonstrated that CASE-based teaching methods significantly enhanced high school student's ability to apply theoretical physics knowledge to practical problems, surpassing the outcomes of traditional instructional approaches. Similarly, research featured in chemistry highlighted CASE's effectiveness in improving undergraduate students' conceptual understanding and problem-solving skills compared to control groups. Outside science disciplines, CASE has also shown a positive impact on student learning (Bibi & Aziz, 2021; Ochagavia, 2014).

The learning process (3)

The Cognitive Acceleration through Science Education (CASE) model provides a structured approach to fostering cognitive development in science education which synergises effectively with LGDM projects (Adey & Shayer, 2015). Through each stage of CASE for LGDM projects, students progress from laying the groundwork of scientific concepts and digital media literacy in Concrete Preparation right through to encountering cognitive conflict while harmonising scientific understanding with digital media creation. This approach can support meaningful learning by using experimental evidence and the social construction of meaning via groupwork to reconstruct critical ideas.

The Social Construct stage emphasises collaborative learning, where students collectively brainstorm ideas, conduct research, and develop an evidence-based storyboard to produce engaging digital media artefacts about scientific concepts. Reasoning skills are promoted throughout the iterative processes of digital media production by applying and repeating reasoning schemas which are carefully guided and scaffolded by the teacher. Metacognition becomes pivotal as students reflect on learning processes and strategies and evaluate their understanding of scientific concepts in the context of digital media creation. Finally, in the Bridging stage, students connect their scientific knowledge with real-world digital media creation, producing artefacts that communicate scientific concepts to broader audiences and demonstrating the relevance of their learning beyond the classroom.

The output of the Funnel Model (4)

At the culmination of the Funnel Model learning experience, students have hopefully acquired many skills beyond conventional boundaries, empowering them to succeed in diverse contexts. By leveraging cognitive acceleration strategies and digital media creation, the proposed model could help students cultivate a multifaceted skill set characterised by deep understanding, schema formation, and integration of knowledge. Students will be expected to explore scientific concepts and digital media principles in depth, engaging in rigorous inquiry to uncover underlying connections. Students will be able to consolidate their learning through the repeated exposure and practice inherent in the iterative nature of digital media production, profoundly embedding knowledge into their long-term memory. They can potentially synthesise insights from incongruent sources, creating narratives that transcend disciplinary boundaries. This process could foster metacognitive development as students will monitor and regulate their thinking with intentionality and self-awareness. Taking ownership of their learning journey, students can exercise their agency and initiative, actively seeking opportunities for exploration and self-directed growth. They can cultivate transferable skills such as communication, collaboration, conflict resolution, and digital media literacy, positioning themselves for success across diverse domains beyond academia.

Addressing the Gaps in Science Education with the Funnel Model

The Funnel Model of Transformative Science Education is designed to address and mitigate common weaknesses in conventional science instructional models by leveraging digital tools and platforms to create interactive learning experiences without the logistical and financial burdens of traditional setups. It incorporates a blended learning approach to training students and educators that combines asynchronous and synchronous teaching methods. From the teacher's perspective, this approach allows them to focus on facilitation and mentoring while freeing up classroom time for personalised instruction. Built around the principles of Learner-Generated Digital Media (LGDM) and Cognitive Acceleration in Science Education (CASE), the Funnel model emphasises scaffolding, peer learning, and collaborative support, reducing the burden on individual teachers and fostering an inclusive learning environment.

LGDM can empower students to create digital media, fostering creativity, self-expression, critical thinking, and digital media literacy skills, providing student agency, and enhancing engagement and ownership of learning outcomes. Additionally, LGDM can take group dynamics into account to ensure all members of each group contribute to a project using a groupwork marking rubric to weight mark allocations according to student effort and contribution. CASE integrates learning into real-world contexts, making education more relevant and applicable to students' lives, improving retention and understanding, and preparing students for practical challenges beyond the classroom. Together, LGDM and CASE can address the shortcomings of current instructional approaches by promoting active student participation, real-world application, and personalised learning experiences tailored to individual needs and interests.

Methodological approach

The validation and refinement of the Funnel Transformative Model of Science Education will be conducted using a Design-Based Research (DBR) methodology and methodological triangulation. The research aims to address three key questions: the characteristics of a model combining LGDM and CASE to tackle current science education challenges, educators' perceptions of implementation challenges and potential improvements, and the model's impact on teachers' readiness to address these challenges. The research will be carried out in four stages: (1) Refinement of the Funnel model through feedback from experienced STEM educators, resulting in Funnel V2; (2) A pilot study with in-service teachers from various disciplines to further refine the model, leading to Funnel V3; (3) Preparation for classroom implementation, including the design of instructional materials, pre/post surveys, and an LGDM assessment with a marking rubric; and (4) Implementation and impact measurement with pre-service teachers, using surveys and LGDM project evaluations to validate and fine-tune the model. This comprehensive and iterative approach ensures the research questions are thoroughly addressed, leading to the effective refinement of the Funnel Transformative Model of Science Education.

The future

The fusion of LGDM and CASE instructional approaches in the Funnel Model could potentially contribute to a transformative era in science education, promising profound impacts on student learning outcomes and instructional practices. This integration prioritises deep conceptual understanding and cognitive development, leveraging CASE's cognitive acceleration techniques in LGDM projects to foster active, inquiry-driven learning experiences. By engaging students in digital media creation, the integration promises to enhance their digital media literacy skills. It could promote interdisciplinary learning, enabling them to contextualise scientific principles within real-world scenarios and prepare for the modern workforce's demands. Moreover, this approach would foster a student-centred learning environment, empowering students to take ownership of their learning journey and actively construct knowledge via autonomous, creative, and self-directed exploration.

References

Adey, P. & Shayer, M. (2015). The effects of cognitive acceleration. *Socializing intelligence through academic talk and dialogue*, 127-140. https://doi.org/10.3102/978-0-935302-43-1_10

Aksela, M. & Haatainen, O. (2019). Project-based learning (PBL) in practise: Active teachers' views of its' advantages and challenges. *Integrated Education for the Real World*, 9-16.

Amano, T., Rios Rojas, C., Boum II, Y., Calvo, M. & Misra, B. B. (2021). Ten tips for overcoming language barriers in science. *Nature Human Behaviour, 5*(9), 1119-1122. https://doi.org/10.1038/s41562-021-01137-1

Aparicio-Ting, F. E., Slater, D. M. & Kurz, E. U. (2019). Inquiry-based learning (IBL) as a driver of curriculum: A staged approach. *Papers on Postsecondary Learning and Teaching, 3*, 44-51. https://doi.org/10.55016/ojs/pplt.v3Y2019.53136

Balci, S., Cakiroglu, J. & Tekkaya, C. (2006). Engagement, exploration, explanation, extension, and evaluation (5E) learning cycle and conceptual change text as learning tools. *Biochemistry and Molecular Biology Education, 34*(3), 199-203. https://doi.org/10.1002/bmb.2006.49403403199

Bergmann, J. & Sams, A. (2012). *Flip your classroom: Reach every student in every class every day*: International Society for Technology in Education.

Bibi, M., & Aziz, S. (2021). Development of Reasoning Skills among Prospective Teachers through Cognitive Acceleration Approach. *Journal of Development and Social Sciences*, 2(4), 330-342. https://doi.org/10.47205/jdss.2021(2-IV)29

Boddy, N., Watson, K. & Aubusson, P. (2003). A trial of the five Es: A referent model for constructivist teaching and learning. *Research in Science Education, 33*, 27-42. https://doi.org/10.1023/A:1023606425452

Chen, L. & Xiao, S. (2021). Perceptions, challenges and coping strategies of science teachers in teaching socioscientific issues: A systematic review. *Educational Research Review, 32*, 100377. https://doi.org/10.1016/j.edurev.2020.100377

Coll, R. K., France, B. & Taylor, I. (2005). The role of models/and analogies in science education: implications from research. *International Journal of Science Education, 27*(2), 183-198. https://doi.org/10.1080/0950069042000276712

Diana, N. & Sukma, Y. (2021). *The effectiveness of implementing project-based learning (PjBL) model in STEM education: A literature review.* Paper presented at the Journal of Physics: Conference Series. https://doi.org/10.1088/1742-6596/1882/1/012146

Ferwati, W., Junaidi, A., Napitupulu, E. & Hamid, A. (2023). Systematic review of literature: Advantages and challenges in implementing the Project-Based Learning (PjBL). *Cendikia: Media Jurnal Ilmiah Pendidikan, 14*(2), 160-166.

Garcia I Grau, F., Valls, C., Piqué, N. & Ruiz-Martín, H. (2021). The long-term effects of introducing the 5E model of instruction on students' conceptual learning. *International Journal of Science Education, 43*(9), 1441-1458. https://doi.org/10.1080/09500693.2021.1918354

Georgiou, H., Nielsen, W., Doran, Y., Turney, A. & Jones, P. (2016). Analysing student-generated digital media in science. In *Proceedings of The Australian Conference on Science and Mathematics Education* (pp. 57-57).

Glynn, S. (2015). Analogies, Role in Science Learning. In: Gunstone, R. (eds) *Encyclopedia of Science Education*. Springer, Dordrecht. https://doi.org/10.1007/978-94-007-2150-0_89

Harding, S. (2023). *Science and social inequality: Feminist and postcolonial issues*: University of Illinois Press.

Hinostroza, J. E., Armstrong-Gallegos, S. & Villafaena, M. (2024). Roles of digital technologies in the implementation of inquiry-based learning (IBL): A systematic literature review. *Social Sciences & Humanities Open, 9*, 100874. https://doi.org/10.1016/j.ssaho.2024.100874

Hmelo-Silver, C. E. (2004). Problem-based learning: What and how do students learn? *Educational Psychology Review, 16*(3), 235-266. https://doi.org/10.1023/B:EDPR.0000034022.16470.f3

Hmelo-Silver, C. E. (2006). Design principles for scaffolding technology-based inquiry. *Collaborative Reasoning, Learning and Technology* (s 147), 170.

Holmes, K., Mackenzie, E., Berger, N. & Walker, M. (2021). Linking K-12 STEM pedagogy to local contexts: A scoping review of benefits and limitations. Paper presented at the Frontiers in Education. https://doi.org/10.3389/feduc.2021.693808

Hoban, G. & Nielsen, W. (2014). Creating a narrated stop-motion animation to explain science: The affordances of “Slowmation” for generating discussion. *Teaching and Teacher Education*, 42, 68-78. https://doi.org/10.1016/j.tate.2014.04.007

Hugerat, M., & Kortam, N. (2014). Improving higher order thinking skills among freshmen by teaching science through inquiry. *Eurasia Journal of Mathematics, Science and Technology Education,* 10(5), 447-454. https://doi.org/10.12973/eurasia.2014.1107a

Hushman, C. J. & Marley, S. C. (2015). Guided instruction improves elementary student learning and self-efficacy in science. *The Journal of Educational Research, 108*(5), 371-381. https://doi.org/10.1080/00220671.2014.899958

Jdaitawi, M. (2019). The Effect of Flipped Classroom Strategy on Students Learning Outcomes. *International Journal of Instruction, 12*(3), 665-680. https://doi.org/10.29333/iji.2019.12340a

Joswick, C. & Hulings, M. (2024). A systematic review of BSCS 5E instructional model evidence. *International Journal of Science and Mathematics Education, 22*(1), 167-188. https://doi.org/10.1007/s10763-023-10357-y

Kaçar, T., Terzi, R., Arıkan, İ. & Kırıkçı, A. C. (2021). The effect of inquiry-based learning on academic success: A meta-analysis study. *International Journal of Education and Literacy Studies, 9*(2), 15-23. https://doi.org/10.7575/aiac.ijels.v.9n.2p.15

Kaptan, K. & Timurlenk, O. (2012). Challenges for science education. *Procedia-Social and Behavioral Sciences, 51*, 763-771. https://doi.org/10.1016/j.sbspro.2012.08.237

Kearney, M., Pressick-Kilborn, K. & Aubusson, P. (2015). Students' use of digital video in contemporary science teacher education. In *Student-generated Digital Media in Science Education* (pp. 136-148). Routledge.

Kelley, T. R. & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM education, 3*, 1-11. https://doi.org/10.1186/s40594-016-0046-z

Kim, B. & Reeves, T. C. (2007). Reframing research on learning with technology: In search of the meaning of cognitive tools. *Instructional Science, 35*, 207-256. https://doi.org/10.1007/s11251-006-9005-2

Koyunlu Ünlü, Z. & Dökme, İ. (2022). A systematic review of 5E model in science education: proposing a skill-based STEM instructional model within the 21st century skills. *International Journal of Science Education, 44*(13), 2110-2130. https://doi.org/10.1080/09500693.2022.2114031

Lombardi, D., Shipley, T. F., Astronomy Team, B. T., Chemistry Team, Engineering Team, Geography Team, Geoscience Team & Team, P. (2021). The curious construct of active learning. *Psychological Science in the Public Interest, 22*(1), 8-43. https://doi.org/10.1177/1529100620973974

McCormack, L., Finlayson, O. E., & McCloughlin, T. J. (2014). The CASE programme implemented across the primary and secondary school transition in Ireland. *International Journal of Science Education*, 36(17), 2892-2917. https://doi.org/10.1080/09500693.2014.938711

McGee, E. O. (2021). *Black, brown, bruised: How racialized STEM education stifles innovation*: Harvard Education Press.

Meissner, B. & Bogner, F. X. (2013). Towards cognitive load theory as guideline for instructional design in science education. *World Journal of Education, 3*(2), 24-37. https://doi.org/10.5430/wje.v3n2p24

Mihic, M. & Zavrski, I. (2017). Professors’ and students’ perception of the advantages and disadvantages of project based learning. *Int. J. Eng. Educ, 33*(6), 1737-1750.

Mizetti, M. d. C. F., Krolow, I. R. C. & Teixeira, M. d. R. F. (2020). Access of indigenous peoples to formal education: science education: a challenge, a reality. *Pro-Posições, 31*, e20170147. https://doi.org/10.1590/1980-6248-2017-0147

Nepeina, K., Istomina, N. & Bykova, O. (2020). The role of field training in STEM education: Theoretical and practical limitations of scalability. *European Journal of Investigation in Health, Psychology and Education, 10*(1), 511-529. https://doi.org/10.3390/ejihpe10010037

Nielsen, W., Hoban, G., & Hyland, C. J. (2017). Pharmacology students’ perceptions of creating multimodal digital explanations*. Chemistry Education Research and Practice*, 18(2), 329-339. https://doi.org/10.1039/C6RP00244G

Nurhidayah, I., Wibowo, F. & Astra, I. (2021). Project Based Learning (PjBL) learning model in science learning: Literature review. Paper presented at the Journal of Physics: Conference Series. https://doi.org/10.1088/1742-6596/2019/1/012043

Ochagavia, B. T. (2014). The experience of using a Cognitive Acceleration approach with prospective primary teachers in Chile (Doctoral dissertation, King's College London).

Oliver, M., & Venville, G. (2015). Cognitive acceleration through science education: The CASE for thinking through science. In *The Routledge international handbook of research on teaching thinking* (pp. 378-387). Routledge.

Ortiz-Revilla, J., Greca, I. M. & Arriassecq, I. (2022). A theoretical framework for integrated STEM education. *Science & Education, 31*(2), 383-404. https://doi.org/10.1007/s11191-021-00242-x

Pirhonen, Juhani and Päivi Rasi (2017). Student-generated instructional videos facilitate learning through positive emotions. *Journal of Biological Education* 51.3: 215-227. https://doi.org/10.1080/00219266.2016.1200647

Reggiani, M., Gagnon, J. D. & Lunn, R. J. (2024). LGBT+ academics' and PhD students' experiences of visibility in STEM: more than raising the rainbow flag. *Higher Education, 87*(1), 69-87. https://doi.org/10.1007/s10734-023-00993-2

Reyna, J. (2021). Digital media assignments in undergraduate science education: an evidence-based approach. *Research in Learning Technology*, 29. https://doi.org/10.25304/rlt.v29.2573

Reyna, J. (2019a). A model to explore learning processes in learner-generated digital media assignments. Paper presented at the 13th International Technology, Education and Development Conference, Valencia, Spain. https://doi.org/10.21125/inted.2019.0015

Reyna, J. (2019b). Surfing the Open Oceans of Flipped Learning: A Comprehensive Student-Centred Model to Implement Flipped Classrooms. Paper presented at the Society for Information Technology & Teacher Education International Conference 2019, Las Vegas, NV, United States.

Reyna, J., Hanham, J. & Meier, P. (2017). A taxonomy of digital media types for Learner-Generated Digital Media assignments. *E-learning and Digital Media, 14*(6), 309-322. https://doi.org/10.1177/2042753017752973

Reyna, J., Hanham, J. & Meier, P. (2018a). A framework for digital media literacies for teaching and learning in higher education. *E-learning and Digital Media, 15*(4), 176-190. https://doi.org/10.1177/2042753018784952

Reyna, J., Hanham, J. & Meier, P. (2018b). The Internet explosion, digital media principles and implications to communicate effectively in the digital space. *E-learning and Digital Media, 15*(1), 36-52. https://doi.org/10.1177/2042753018754361

Reyna, J., Hanham, J., Vlachopoulos, P. & Meier, P. (2019). A Systematic Approach to Designing, Implementing, and Evaluating Learner-Generated Digital Media (LGDM) Assignments and Its Effect on Self-regulation in Tertiary Science Education. *Research in Science Education*. https://doi.org/10.1007/s11165-019-09885-x

Reyna, J. & Meier, P. (2018). Using the Learner-Generated Digital Media (LGDM) Framework in Tertiary Science Education: A Pilot Study. *Education Sciences, 8*(3), 106. https://doi.org/10.3390/educsci8030106

Reyna, J., Meier, P., Geronimo, F. & Rodgers, K. (2016). Implementing Digital Media Presentations as Assessment Tools for Pharmacology Students. *American Journal of Educational Research, 4*(14), 983-991.

Reyna, J., Meier, P., Hanham, J., Vlachopoulos, P. & Rodgers, K. (2017). Learner-Generated Digital Media (LGDM) Framework. Paper presented at the INTED2017, Valencia (Spain), 6-8 March 2017. https://doi.org/10.21125/inted.2017.2080

Roth, K. J. (2013). Developing meaningful conceptual understanding in science. In *Dimensions of thinking and cognitive instruction* (pp. 139-175): Routledge.

Savery, J. R. (2015). Overview of problem-based learning: Definitions and distinctions. *Essential readings in problem-based learning: Exploring and extending the legacy of Howard S. Barrows, 9*(2), 5-15. https://doi.org/10.2307/j.ctt6wq6fh.6

Seneviratne, K., Hamid, J. A., Khatibi, A., Azam, F. & Sudasinghe, S. (2019). Multi-faceted professional development designs for science teachers' self-efficacy for inquiry-based teaching: a critical review. *Universal Journal of Educational Research, 7*(7), 1595-1611. https://doi.org/10.13189/ujer.2019.070714

Sarwar, S., & Samiullah, M. (2021). The Effect of Cognitive Acceleration Programme on Critical Thinking of Science Students at Secondary Level. *International Journal of Innovation in Teaching and Learning* (IJITL), 7(2), 87-100. https://doi.org/10.35993/ijitl.v7i2.1516

Seleznyov, S., Adhami, M., Black, A., Hodgen, J., & Twiss, S. (2022). Cognitive acceleration in mathematics education: Further evidence of impact. *Education* 3-13, 50(5), 564-576. https://doi.org/10.1080/03004279.2021.1872678

Shayer, M. (1999). Cognitive acceleration through science education II: Its effects and scope. *International Journal of Science Education, 21*(8), 883-902. https://doi.org/10.1080/095006999290345

Suprapto, N. (2020). Do we experience misconceptions?: An ontological review of misconceptions in science. *Studies in Philosophy of Science and Education, 1*(2), 50-55. https://doi.org/10.46627/sipose.v1i2.24

Thomas, G. P. & Boon, H. J. (2023). *Challenges in science education: Global perspectives for the future*: Springer Nature. https://doi.org/10.1007/978-3-031-18092-7

Wei, B. & Chen, Y. (2020). Integrated STEM education in K-12: Theory development, status, and prospects. *Theorizing STEM Education in the 21st Century*, 1-12. https://doi.org/10.5772/intechopen.88141

Reyna, J., Romero Ariza, M., & Quesada Armenteros, A. (2024). The Funnel Transformative Model of Science Education: An Innovative Approach Awaiting Validation. In Cochrane, T., Narayan, V., Bone, E., Deneen, C., Saligari, M., Tregloan, K., Vanderburg, R. (Eds.), *Navigating the Terrain: Emerging frontiers in learning spaces, pedagogies, and technologies*. Proceedings ASCILITE 2024. Melbourne (pp. 12-22). https://doi.org/10.14742/apubs.2024.1046