

CENTERIS – International Conference on ENTERprise Information Systems / ProjMAN – International Conference on Project MANagement / HCist – International Conference on Health and Social Care Information Systems and Technologies 2022

Science education through project-based learning: a case study

Carolina Santos^{a,b,*}, Eliza Rybska^c, Michal Klichowski^d, Barbara Jankowiak^d, Sylwia Jaskulska^d, Nuno Domingues^e, Diana Carvalho^{f,g}, Tânia Rocha^{f,g}, Hugo Paredes^{f,g}, Paulo Martins^{f,g}, João Rocha^{a,b}

a National School of Public Health- NOVA University of Lisbon, Avenida Padre Cruz, Lisbon 1600-560, Portugal

b Comprehensive Health Research Centre, NOVA University of Lisbon, Lisbon, Portugal

c Faculty of Biology- Adam Mickiewicz University, Uniwersytetu Poznańskiego 6, Poznan 61-614, Poland

d Faculty of Educational Studies- Adam Mickiewicz University, Szamarzewskiego 89, Poznan 60-568, Poland

e Instituto Politécnico de Lisboa- Instituto Superior de Engenharia de Lisboa, Rua Conselheiro Emídio Navarro 1, Lisbon 1959-007, Portugal

f Institute for Systems and Computer Engineering, Technology and Science, Rua Dr. Roberto Frias, Porto 4200-465, Portugal

g University of Trás-os-Montes e Alto Douro, Quinta de Prados, Vila Real 5001-801, Portugal

Abstract

Partnerships for Science Education (PAFSE) is a case study of project-based learning applied to real-world problems connected with public health and sustainable development. The EU-funded project organizes science education activities at low secondary level engaging students and school stakeholders (universities, research centres, start-ups, enterprises, governmental organisations, NGOs) in health promotion and disease prevention actions that benefit the health and well-being of the community. Projects leaded by schools are addressed within educational scenarios co-created with partners interested in STEM education and developed under a relevant public health issue through their continuous engagement in open schooling approach.

© 2023 The Authors. Published by Elsevier B.V.

This is an open access article under the CC BY-NC-ND license (<https://creativecommons.org/licenses/by-nc-nd/4.0>)

Peer-review under responsibility of the scientific committee of the CENTERIS – International Conference on ENTERprise Information Systems / ProjMAN - International Conference on Project MANagement / HCist - International Conference on Health and Social Care Information Systems and Technologies 2022

Keywords: Project-based learning; inquiry-based learning; public health education; open schooling; project management; scientific evidence

* Corresponding author. Tel.: +351 9645-842-64.

E-mail address: c.santos@ensp.unl.pt

1. Introduction

The societal burden generated by the COVID-19 pandemic combined with the increasing burden of non-communicable diseases laid public health education in the spotlight, as it can boost awareness about risk factors, healthy behaviour, determinants of health, and their relationship with living environments. The pandemic has also shown that scientific research and innovation can be a complex and slow process, with inherent uncertainty in research findings. To promote science education is crucial to help communities to be ready to better manage public health risks in the future, in collaboration with stakeholders, schools, students and their families. Partnerships for Science Education (PAFSE) is a project that uses project-based learning (PBL) to address this research problem, promoting that students at low secondary level make informed choices regarding their health, and strengthening schools capacity to promote Science, Technology, Engineering, Mathematics (STEM) learnings with a focus on public health, in partnership with community stakeholders, thus advocating for an open schooling framework. The project will enhance the readiness of communities in the public health perspective, will strengthen the level of responsibility and proactiveness of young people and citizens in participating in public health-related measures and will also improve the collaboration between stakeholders, schools and their communities to the benefit of education and wellbeing.

The purposes of PAFSE project are to create collaborative educational partnerships between schools, educational providers, and other relevant community actors; promote STEM education; contribute to preparedness and scientific literacy at the community level on public health challenges; create science education clusters supported by stakeholders; create science education clusters in the European (EU) partners' countries; and increase students' competence to engage in project-based learning.

PAFSE rises the competency of students to engage in project-based learning on significant public health problems, enhances the levels of scientific literacy and preparedness at the community level, and introduces health education actions in formal and informal learning environments (e.g., classroom, science clubs, social organizations, parents' associations). A web-based environment for collaboration and dissemination that encloses educational resources and teaching-learning experiences was developed to develop project management and inquiry-based competencies. By creating education clusters that promote innovative ways of providing STEM learning, through partnerships with stakeholders (universities, municipalities, enterprises, associations, etc.) and with the involvement of the local community, PAFSE also promotes school projects that benefit the health of the school community, and the sustainability of open schooling approaches to health education and community preparedness for public health hazards.

The project challenges students and schools to take a role in their community preparedness for major problems by implementing educational scenarios within science networks. Through project-based learning and digital learning packages embracing relevant topics (e.g., zoonosis, social and environmental determinants of health, non-communicable diseases, child obesity, pollution, green mobility, sustainable development goals), the project engages a wide range of actors in innovative teaching-learning activities, promotes health literacy at school community and engages local stakeholders in collaborative science education activities. PAFSE will involve more than 3000 students and their families in the project activities and the outcomes will be disseminated to more than 1000 schools.

The aim of this paper is to present the PAFSE project and its objectives, and to discuss how the project integrates project-based learning to engage students in analyzing public health topics. This paper is organized as follows: section 2, background, with a literature review of project-based and inquiry-based learning; section 3, providing a description of the methodology; section 4, with the educational scenarios topics, how project-based learning is addressed in each case, and how scenarios are enacted; section 5, bringing up the conclusions of the article, and what is the future work within the PAFSE project.

2. Background

The development of critical thinking is facilitated when students have the opportunity to participate in problem-solving and knowledge generation in authentic situations and evidence suggests that PBL is a valid approach to conduct this pathway. PBL is an approach to teaching in which students address real-world challenges, through an inquiry-based instructional method, to accomplish meaningful projects, thus engaging in knowledge construction. Inquiry-based competencies are key attributes for individuals to think by themselves, and to engage critically with useful publicly available information regarding relevant topics. PBL includes a driving question, collaboration among

students, the use of scaffolding technologies, a strong emphasis on critical thinking and communication skills, and interdisciplinary learning [1–4].

PBL sets on the multi-stage learning concept. So, it is built on Aristotle's assumption that learning has to crisscross three areas: (1) sensuality and percipience, (2) wit and thinking, and (3) ambition and desire. For this Aristotelian assumption to be fulfilled, the learner has to solve problems and cooperate [5]. Therefore, and according to the classification created by Merriam and collaborators (2012) [6], PBL is a consensus approach between the theories of learning classified as western theories, which focus on individuality and independence, and eastern theories, promoting collectivism and belonging [7]. In other words, PBL is embedded in constructivism [8] that focuses on active inquiry and experience and, at the same time, on collaboration [9].

Inquiry-based science education (IBSE) serves as an umbrella concept for many teaching and learning approaches that share some common features. Among them, we can distinguish students' active engagement with an emphasis on supporting knowledge claims with observations, experiments, experiences, or complementary sources of credible evidence, tackling authentic and problem-based learning activities, and developing the skills of systematic observation, questioning, planning and recording with a purpose to obtain credible evidence. IBSE has been proposed as a framework for creating a learning environment in which we observe a shift from teacher to student-centered class design and development of peer-teaching, peer-assessment, problem and PBL [10,11]. It is claimed that IBSE has the potential to provide students with authentic experiences of how scientists work (e.g., Brickhouse, 2008 [12]). When taking into account the idea that teaching and learning science should resemble the way science is done at the universities while implementing IBSE into a school environment, we might observe such activities as doing experiments with stating a research problem and hypothesis, gathering and scientifically analyzing data, discussing and formulating arguments, forming and providing evidence for claims, or peer process of reviewing and formulating feedback [11]. Gormally and co-authors (2009) [10] have shown in their research greater improvements in students' science literacy and research skills using inquiry lab instruction. This effect occurred together with increasing students' self-confidence in scientific abilities, although this gain was more significant in a traditional teacher-center lab setting.

Indeed, PBL requires that students have a high degree of responsibility, autonomy, and unsupervised work time when engaging in the projects [4], thus teachers must provide enough support for students and launch driven questions to develop their projects, while maintaining appropriate distance. Students participate in a goal-directed process of inquiry, knowledge building, and problem resolution, in projects that are authentic regarding their topics, the context in which the project is developed, and tasks carried out by students [4]. Students are provided with tools to collect information and analyse evidence, while exposed to peer feedback and the critique of friendly experts.

Research has demonstrated that PBL can be an effective approach to engage and motivate middle grades learners [13], and when they are allowed to choose to topic they will explore, representing a problem of relevance to their personal lives, they become intrinsically motivated to dedicate themselves to the work and aim for high quality [14]. When thoughtfully designed and implemented, evidence suggests that project-based learning can be more effective than traditional educational approaches regarding supporting long-term knowledge retention, improving mastery of 21st century skills, and preparing students to synthesize and explain concepts [14–16]. Students' achievements grow not only to the extent to which the project concerns, but also in other areas of knowledge. Work on the project triggers learning understood as the accumulation of substantive knowledge, but also horizontal learning acquiring or improving skills that will be used in others non-project situations [17].

Some studies suggest that PBL positively influences students' performance, retention, interest and self-efficacy across elementary, secondary and postsecondary levels [4,18–21]. A 20-year meta-analysis compared the effects of project-based learning and teachers' direct instruction on the academic achievement of students in different levels of education, finding better effects for PBL [22]. Although project-based learning activities may take time away from traditional lectures, research suggests that is does not dissuade the learning of the course content [23], and generally it is positively received by educators [24]. For STEM disciplines, project-based learning is seen as a powerful approach for learning due to inclusion of authentic tasks [25].

Project-based implementation in educational settings brings challenges: students must take responsibility for the learning process, while receiving appropriate support and tools to develop their projects, therefore the learning environment and teaching practices must be designed with intention to support students' self-regulated learning [26–29]. In addition, a high-quality group process is important for effective project-based learning [30]. These processes include positive interdependence, individual accountability, equal participation, and social skills [31,32]. It means that each group member needs the others to succeed, has an equal share of work, and the group's success depends on the individual learning of all members. Social skills in communication, decision-making, trust-building, and conflict

management are essential in PBL [30]. For secondary education, project-based learning in the STEM context requires integration across various disciplines, while subject areas are commonly not connected with each other but strongly disconnected [33]. Older students thanks to STEM have a better understanding of the problem-solving process [34].

In order to be successful in project-based learning, students must take responsibility for the learning process by setting goals, monitoring, reflecting, and sustaining their motivation from the beginning of the project until the end. However, these processes do not occur naturally or easily for many students. Therefore, the learning environment and teaching practices in project-based learning must be designed with intention to support students' self-regulated learning and describes specific learning environment features and teaching practices to foster student responsibility for learning in each phase of PBL [26–29].

3. Methodology

Following inquiry and project-based learning as key approaches for skills development, the educational scenarios - integrated instructional and learning units that propose structured ways for organizing the teaching-learning process - engage students, teachers and the entire school community in research projects developed under a major public health topic, such as zoonoses, epidemics, social determinants of health, oral diseases, road traffic accidents, diabetes, infectious diseases, vaccine hesitancy, sustainable development. The identification of themes was based on: a) national curriculums, b) evidence on the major public health challenges society faces, c) consultation of experts and advisory group of PAFSE (e.g.: teachers, national directorates for education). Every scenario includes learning goals, digital learning objects, a teaching-learning script with lessons plans, assessment methods, supplementary learning activities and a guide for school-based projects under the topic. The scripts bring STEM professionals to the classroom (e.g., researchers, public health specialists, engineers, project managers) and challenge students to manage projects and present their results in open-schooling events.

4. Results

Novel educational scenarios linking science education with public health challenges are piloted in 2022 and 2023 within educational hubs connecting formal and non-formal educational providers interested in STEM (schools, science clubs, municipalities, start-ups, enterprises, research centers, universities, libraries, open science platforms, etc.) initially hosted in the European (EU) partners' countries (Portugal, Greece, Cyprus, Poland). The seven clusters result from initial partnerships between schools, consortium members, and local stakeholders in a couple of EU cities (Lisbon, Vila Real, Braga, Athens, Ioannina, Nicosia, Poznan) and will grow from local to international networks with the progressive commitment of organizations established at the EU level. At the moment, 27 scenarios and inquiry-based projects for public health education are under development, in peer review or piloting process. Teachers are prepared to activate the scenario in professional development workshops, which provides advice on project management, design and administration, data analysis and reporting, and supports in the organization of school public events, one for each project that will be implemented. Students are engaged by teachers in conducting empirical studies, such as surveys and observations, collecting evidence on the local community perceptions, beliefs, attitudes and behaviour, and are supported with project management tools with a defined structure for management, design and administration of their projects, so that they can produce proposals for community health and well-being communicated in the events. These 27 public events taking place at the EU level represent an effort for the school and the local partnership to reach out to the community to inform them about their project and to discuss the issue related to public health that was selected for the scenario.

Each scenario enacted will culminate in a open schooling event, in which students will present their projects to the local community, will debate and advocate for actions, ideas, and policies that promote better conditions for their communities. Table 1 presents some of the scenarios to be enacted and the school research project that will be implemented in each of them.

Table 1. PAFSE Scenarios and School Research Projects.

Topic	School Research Project
Looking after myself and others – Healthy Eating	Students collect data from a variety of inquiry-based sources about the causes, health risks and solutions related to childhood obesity, and about individuals' and governments' responsibility for reducing childhood obesity. Students organize and hold a forum for a discussion about childhood obesity and proposal of solutions.
The mathematical representation of an epidemic: the case of SIR (Susceptible, Infectious, or Recovered) modelling	Students apply SIR models to propose and test public health interventions for the effective administration of an epidemic outbreak. Students develop and disseminate informative material that highlights the importance of non-pharmaceutical interventions for the promotion of public health.
Social determinants of health during an epidemic/pandemic outbreak	Students develop a research instrument to understand the effect of the COVID-19 pandemic on the local society. The empirical social research includes data collection, analysis and interpretation, using the proper techniques for handling qualitative or quantitative data. Students present and communicate their findings at a school event.
Function of vaccines, vaccination hesitancy and misinformation	Students create a guide for detecting cases of medical misinformation, through composition of scientific facts, data and arguments concerning the necessity for vaccination. Students disseminate their results by designing a pro vaccination campaign for the general public.
Road traffic crashes – a public health issue	Students build and present a poster/infographic about their school community mobility patterns and its impacts on environment, health and road safety. Students calculate road safety indicators through roadside observations for risky behaviours as a pedestrian, cyclist, motorcyclists/moped rider, car passengers, and/or car driver.
3D modelling to address pandemic challenges	Students propose solutions for 3D modelling of basic objects, identifying their importance to address pandemic challenges but also the role of innovation. Students present the 3D models in a community setting and pitch how 3D modelling can address pandemic challenges.
Droplets & the physics of viruses transmission	Students develop simulations about physical process of droplet transmission on computational tools and evaluate different health outcomes. Students present project outputs in a community setting and discuss how the incidence of diseases transmitted by air are influenced by individual behaviour and environmental factors.
Noise pollution and quality of life	Students identify sources of noise pollution in different environments, using sound level meters, and based on research, critically evaluate the consequences of noise pollution on human beings. Students make recommendations for reduction of noise in public spaces and disseminate their recommendations.
The role of environment and animal health in zoonotic diseases and pandemics	Students perform inquiry-based activities in the community, build an infographic about climate change, environmental determinants of health, zoonoses, and present their findings in a community setting, with suggested action for community leaders and policy makers.
Non-communicable diseases	Students perform inquiry-based activities in the community to study the social and environmental issues around the incidence of non-communicable diseases and present an infographic in a community setting. Students suggest action for community leaders and policy makers.
Sustainable Development Goals	Students study how SDGs improvement are associated to positive outcomes in the school environment and community. Students conduct inquiry-based activities to produce infographics to be presented in community settings and communicate evidence-based recommendations.
Artificial Intelligence responses when clinical symptoms appear	Students build a website that contains a chatbot to address the actions to be taken when they have symptoms. Students present the website and chatbot in a public event, and disseminate evidence-based recommendations via social, community and mainstream media.
Planet of viruses	Students will answer to questions such as: What is the virus? Why, with their simple structure, they can create such complex relationships. Students will conduct an experiment that demonstrates why is it worth washing hands with soap and water, with results presented to the school community and the younger pupils.
Vaccines - our weapons in the fight against microbes	Students perform inquiry-based activities in their classroom and in the community, building an infographic about the influence of vaccination on human life, including statistical analysis of available data. They will present the findings in a community setting, with suggested action for community leaders and policymakers.
Different shades of bacteria	Students carry on the project in which they examine the best condition for lactic fermentation in yogurt production or when pickling, for example, cucumbers. They learn how to carry-on projects, gather scientific data, and use computer equipment, and in the end, they present output to the school community.

The educational scenarios contain the elements necessary for the effective development of these projects, such as integration of disciplines, scaffolding tools and feedback and support by teachers and other stakeholders involved in

supplementary activities, and an inclusive educational platform with digital learning objects to support students' self-regulated learning.

The PAFSE consortium is exceptionally suited to conduct this project as it combines a variety of strengths that are critical for the success of the project, such as expertise in different fields, focus in developing activities in dynamic networks, experience in science education research and school-based teaching-learning, and international experience in European projects.

A risk analysis was conducted, and actions to mitigate such risks were identified, as presented in Table 2.

Table 2. Critical Implementation risks and mitigation actions

Risk	Risk level	Mitigation action
Low adherence to PAFSE project by schools	Medium	Early identification and contact with Directorates for Education to find alternatives to implement the pilot enactments.
Low adherence to the project by teachers	Medium	Early identification and contact with Directorates for Education (and other governance structures for science education available at each country and their networks) to invite other participants to the workshops and webinars.
Low participation of students in surveys and observations to be conducted at the community (research project)	High	Early identification and pre-contact with parents through the participating schools.
Low participation in Public Debate and Recommendations	Low	Formal invitations, pre-contact, need to confirm attendance and fill application form. Early identification and pre-contact with the people invited to participate who have not confirmed participation. Presentation of clear incentives of the project to the community.
Low response rate to online participant surveys	Medium	Reminders by email and mobile phone. Find additional settings and personalized approach to fill the questionnaires.
Delays in individual Work Packages (WPs) that may affect the progress of the project at large and deadlines of achievements, and especially of WPs and tasks that are dependent on the delayed WP	Low	Strong supervisory role of the coordinator, backed up by the Steering Committee and Advisory Board, who may give binding advice. Clear milestones set at months corresponding to consortium meetings. Proactivate measures to avoid and cope with common sources of delay, such as timely recruitment of new personnel. Measures to temporarily reduce dependency between specific WPs, such as redirecting tasks between WP leaders.

5. Conclusions and future work

PBL in school environments supports the design of high-quality inquiry projects related to Public Health Education that guide students in collecting evidence and engaging the local community in open discourse processes. It also provides relevant conditions for global support on action-research community projects led by schools. The PAFSE education model serves not only as a context for building students' competences on project management and on processing scientific evidence, but also for engaging schools and communities in tackling public health issues from a scientific perspective. The strong expertise of the PAFSE consortium in both project management and in the public health topics addressed is a great strength to assure that the full potential of project-based learning is reached. Furthermore, schools and teachers will receive high-quality training to enact the educational scenarios, providing enough support to students, while allowing them to also work independently. Teachers will also identify the different levels of expertise among students, to guarantee that the less experienced ones have higher support from teachers and colleagues. Given that project-based learning brings some challenges (e.g., students taking responsibility for the learning process, the need of positive interdependence, individual accountability, equal participation, and social skills), the piloting phase will be crucial to further developments of the learning scenarios and learning points in the scale-up of PAFSE project.

In the proposed educational scenarios, students, by participating in doing projects, not only go beyond provided information, but the learning process also takes place outside classrooms. Students share the results of their work with other students, their parents, local community members, and community leaders and policymakers. This approach creates opportunities for building an open schooling environment. In PBL, students are protagonists and have an active voice. That means they need to develop autonomy. To do so, they must decide the paths to follow in their projects, recounting the guidance of the teacher. The time to present the completed project is critical for students. This encourages communication and leadership, while encouraging them to evolve into next projects. At the end, students are the center of PBL.

After the piloting of the novel educational scenarios in 2022 and 2023 within educational hubs, these will be evaluated and refined. Then, PAFSE consortium will set a gradual process of network expansion and scale-up of teacher professional development actions at national and EU level, driving exploitation of the project products and experiences.

Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101006468.

Disclaimer: The sole responsibility for the content on this publication lies with the authors. It does not necessarily reflect the opinion of the European Research Executive Agency (REA) or the European Commission (EC).

References

1. Unaizahroya I, Maryani E, Ratmaningsih N. Curriculum Integration Across Subjects in Secondary Schools Through Project-Based Learning. *Saintekno J Sains dan Tekno*. 2022;20(1).
2. Shahrizoda T. Project-Based Learning as an Effective Teaching Method. *J Ethics Divers Int Commun*. 2022;2(2):54–6.
3. Markham T, Larmer J, Ravitz J. Project based learning handbook: A guide to standards-focused project based learning for middle and high school teachers. Buck Institute for Education; 2003.
4. Thomas JW. A review of research in project-based learning. San Rafael, CA: Autodesk Foundation; 2000.
5. Schmoelz A, Swertz C, Forstner A, Barberi A. Does artificial tutoring foster inquiry based learning? *Sci Educ Int*. 2014;25:123–9.
6. Merriam S, Caffarella R, Baumgartner L. Learning in adulthood: A comprehensive guide. San Francisco: John Wiley & Sons; 2012.
7. Akyol Z, Garrison DR. Community of inquiry in adult online learning: Collaborative-constructivist approaches. In: T.T. Kidd & J. Keengwe, editor. *Adult learning in the digital age: perspectives on online technologies and outcomes* (pp 52-66). Hershey – New York: Information Science Reference.; 2009.
8. Chai CS, Wong L-H, King RB. Surveying and Modeling Students' Motivation and Learning Strategies for Mobile-Assisted Seamless Chinese Language Learning. *Educ Technol Soc*. 19:170–80.
9. Klichowski M. Learning in CyberParks. A theoretical and empirical study. Poznan: Adam Mickiewicz University Press; 2017.
10. Gormally C, Brickman P, Hallar B, Armstrong N. Effects of Inquiry-based Learning on Students' Science Literacy Skills and Confidence. *Int J Scholarsh Teach Learn*. 2009;3(2):44–58.
11. Constantinou CP, Tsivitanidou OE, Rybska E. What Is Inquiry-Based Science Teaching and Learning? In: *Professional development for inquiry-based science teaching and learning* [Internet]. Springer, Cham; 2018. p. 1–23. Available from: http://link.springer.com/10.1007/978-3-319-91406-0_1
12. Brickhouse N. What is Inquiry? To whom should it be authentic? In: R. Duschl & E. Grandy, editor. *Teaching scientific inquiry Recommendations for research and implementation*. Rotterdam, The Netherlands/Taipei, Taiwan: Sense Publishers; 2008.
13. Yetkiner ZE, Anderoglu H, Capraro RM. Research summary: Project-based learning in middle grades mathematics. 2008; Available from: <http://www.nmsa.org/Research/ResearchSummaries/ProjectBasedLearninginMath/tabid/1570/Default.aspx>
14. De Vivo K. A new research base for rigorous project-based learning. *Phi Delta Kappan* [Internet]. 2022 Feb 3;103(5):36–41. Available from: <http://journals.sagepub.com/doi/10.1177/00317217221079977>
15. Strobel J, van Barneveld A. When is PBL More Effective? A Meta-synthesis of Meta-analyses Comparing PBL to Conventional Classrooms. *Interdiscip J Probl Learn* [Internet]. 2009 Mar 24;3(1). Available from: <https://docs.lib.purdue.edu/ijpbl/vol3/iss1/4>
16. Boaler J. Learning from Teaching: Exploring the Relationship between Reform Curriculum and Equity. *J Res Math Educ* [Internet]. 2002 Jul;33(4):239–58. Available from:

- <https://www.jstor.org/stable/10.2307/749740?origin=crossref>
17. Helle L, Tynjälä P, Olkinuora E. Project-Based Learning in Post-Secondary Education – Theory, Practice and Rubber Sling Shots. *High Educ* [Internet]. 2006 Mar;51(2):287–314. Available from: <http://link.springer.com/10.1007/s10734-004-6386-5>
 18. Bilgin I, Karakuyu Y, Ay Y. The Effects of Project Based Learning on Undergraduate Students' Achievement and Self-Efficacy Beliefs Towards Science Teaching. *EURASIA J Math Sci Technol Educ* [Internet]. 2015 Apr 29;11(3). Available from: <https://www.ejmste.com/article/the-effects-of-project-based-learning-on-undergraduate-students-achievement-and-self-efficacy-4397>
 19. Brown SW, Lawless KA, Boyer MA. Promoting Positive Academic Dispositions Using a Web-based PBL Environment: The GlobalEd 2 Project. *Interdiscip J Probl Learn*. 2013;7(1).
 20. Holmes V-L, Hwang Y. Exploring the effects of project-based learning in secondary mathematics education. *J Educ Res*. 2016 Sep 2;109(5):449–63.
 21. Torres JW, Saterbak A, Beier ME. Long-term impact of an elective, first-year engineering design course. *ASEE Annu Conf Expo*. 2016;
 22. Chen C-H, Yang Y-C. Revisiting the effects of project-based learning on students' academic achievement: A meta-analysis investigating moderators. *Educ Res Rev* [Internet]. 2019 Feb;26:71–81. Available from: <https://linkinghub.elsevier.com/retrieve/pii/S1747938X19300211>
 23. Beier ME, Kim MH, Saterbak A, Leautaud V, Bishnoi S, Gilberto JM. The effect of authentic project-based learning on attitudes and career aspirations in STEM. *J Res Sci Teach* [Internet]. 2019 Jan 21;56(1):3–23. Available from: <https://onlinelibrary.wiley.com/doi/10.1002/tea.21465>
 24. Habók A, Nagy J. In-service teachers' perceptions of project-based learning. *Springerplus* [Internet]. 2016 Dec 26;5(1):1–14. Available from: <http://www.springerplus.com/content/5/1/83>
 25. Capraro RM, Slough SW. Why PBL? Why STEM? Why now? An Introduction to STEM Project-Based Learning. In: *STEM Project-Based Learning* [Internet]. Rotterdam: SensePublishers; 2013. p. 1–5. Available from: http://link.springer.com/10.1007/978-94-6209-143-6_1
 26. Tzanavaris S, Kavvadia A, Vlizos S, Poulos M. Culture, Learning, and Information and Communication Technologies: Project-Based Learning with Formative Interventions in Authentic Activities. *Hum Arenas* [Internet]. 2022 Jul 13; Available from: <https://link.springer.com/10.1007/s42087-022-00296-5>
 27. Kong Y, Wang C. The effects of self-efficacy on the use of self-regulated learning strategies and project-based writing performance. *Int J English Acad Purp Res Pract* [Internet]. 2022 Mar 1;2022(Spring):21–39. Available from: <https://www.liverpooluniversitypress.co.uk/doi/10.3828/ijeap.2022.3/>
 28. Wirzal MDH, Halim NSA, Md Nordin NAH, Bustam MA. Metacognition in Science Learning: Bibliometric Analysis of Last Two Decades. *J Penelit dan Pengkaj Ilmu Pendidik e-Saintika* [Internet]. 2022 Mar 25;6(1):43–60. Available from: <https://journal-center.litpam.com/index.php/e-Saintika/article/view/665>
 29. English MC, Kitsantas A. Supporting Student Self-Regulated Learning in Problem- and Project-Based Learning. *Interdiscip J Probl Learn* [Internet]. 2013;7(2). Available from: <https://docs.lib.purdue.edu/ijpbl/vol7/iss2/6>
 30. Wing-yi Cheng R, Lam S, Chung-yan Chan J. When high achievers and low achievers work in the same group: The roles of group heterogeneity and processes in project-based learning. *Br J Educ Psychol* [Internet]. 2008 Jun;78(2):205–21. Available from: <http://doi.wiley.com/10.1348/000709907X218160>
 31. Kagan S. Cooperative learning. San Clemente, Kagan Cooperative Learning; 1994.
 32. Johnson DW, Johnson RT, Holubec EJ. Circles of learning. Interaction Book Company; 1993.
 33. Shernoff DJ, Sinha S, Bressler DM, Ginsburg L. Assessing teacher education and professional development needs for the implementation of integrated approaches to STEM education. *Int J STEM Educ* [Internet]. 2017;4(1):13. Available from: <http://stemeducationjournal.springeropen.com/articles/10.1186/s40594-017-0068-1>
 34. Tinh TT, Quang LH. Integrating art with STEAM education - STEAM education in Vietnam high schools. *Ann Comput Sci Ser*. 2019;17.