Integrating Biomimicry in STEM Lessons:

Influence on Student Engagement in and Perception of STEM Learning and Careers

Department of Teacher Education
Master's thesis
Author:
Siddharth Gurjar

30.4.2025
Turku

Master's thesis

Subject: Educational Science
Author(s): Siddharth Gurjar

Title: Integrating Biomimicry in STEM Lessons: Influence on Student Engagement in and Perception of STEM Learning and Careers
Supervisor(s): Prof. Dr. Çiğdem Haser
Number of pages: 62 pages
Date: 30.4.2025

Abstract.

As STEM education gains global prominence for equipping students with 21st-century skills, innovative pedagogical approaches are needed to address declining student interest and engagement. Biomimicry—an interdisciplinary design approach that draws inspiration from nature—offers potential for making STEM learning more relevant and engaging. This study investigates the influence of integrating biomimicry into STEM lessons on fifth-grade students' engagement and their perceptions of STEM learning and careers. Using a mixed-methods quasi-experimental design, the study was conducted in a Finnish comprehensive school with 26 students from two different classrooms which were assigned as a treatment and a control group. The treatment group participated in a six-lesson unit focused on designing and testing catapults inspired by biological systems. The control group continued with their regular instruction. Data were collected through pre- and post-intervention STEM Semantics Surveys, systematic classroom observations, and a post-intervention teacher interview. Quantitative findings revealed no statistically significant differences in students' perceptions of STEM subjects or careers between the treatment and control groups. However, qualitative data indicated increased behavioural engagement during the biomimicry-integrated lessons, especially among students who were previously disengaged. The project-based and hands-on nature of the lessons appeared to foster enthusiasm, collaboration, and deeper participation. Nonetheless, limited duration, introductory exposure, and challenges in conceptual integration constrained broader attitudinal shifts. The study concludes that while biomimicry can enhance student engagement in STEM classrooms, its potential to influence engagement in STEM learning and careers depends on deeper curricular integration, sustained instructional time, teacher professional development, and partnerships with industry professionals to ground learning in real-world contexts.

Key words: STEM education, biomimicry, perceptions, student engagement, STEM careers, Finland, primary students

Table of contents

List of Tables

List of Figures

List of Abbreviations

ACS	Application, Career Connections, Societal Impact
CG	Control group
DBL	Design-based learning
EG	Experimental (treatment) group
FNAE	Finnish National Agency for Education
GDPR	General Data Protection Regulation
IBL	Inquiry-based learning
iSTEM	Integrated STEM
NCC	National Core Curriculum
PBL	Project-based learning
PD	Professional development
Q&A	Question & answer
STEM	Science, Technology, Engineering, and Mathematics
TENK	Tutkimuseettinen neuvottelukunta (Finnish National Board on Research Integrity)

1 Introduction

In a world which is characterised by fast evolving technologies and their impact on human lives, becoming technology literate is no more limited to knowing how to use the technology. Knowing how the technology works can determine if one can use the technology to one's advantage or one is a victim of the technology. Take the case of a recent incidence in the UK when a British Indian teenage student was detained and tried in Spain after he apparently jokingly sent a message about blowing up a plane and being part of a terrorist organisation and was fined a hefty 95.000 euros for the expenses incurred in investigating the case (The Statesman, 2024). Had he known that messages are screened using machine learning algorithms in highly sensitive places such as airports, he would have known better to be careful about what he wrote to his friends. Or consider the ease with which one's identity can be searched for (Moshayedi et al., 2022) and thus can be abused using facial recognition tools easily available to anyone with internet access. On the other hand, technology is helping improve lives by managing traffic (Ouallane et al., 2022), or monitoring patients (Shaik et al., 2023). Technology has implications for education too.

Governmental, business, and educational organizations are increasingly recognising the importance of STEM (Science, Technology, Engineering, and Mathematics) education in meeting 21st century demands. STEM Education aims to eliminate segregating subjects such as natural sciences and mathematics (Kennedy & Odell, 2014) and introduce students to technology and engineering from early on. Kennedy and Odell (2014, p.246) assert that:

> *"Engaging students in high quality STEM education requires programs to include rigorous curriculum, instruction, and assessment, integrate technology and engineering into the science and mathematics curriculum, and also promote scientific inquiry and the engineering design process."*

Fast developing technologies and thereby social landscape require that not only future STEM professionals, but also everyone else needs to be skilled in various skills such as collaboration, effective communication, creativity, critical thinking, and problem solving (Tuong et al., 2023).

As a result of the technological advancement present occupations are changing, newer ones are developing, and others are disappearing altogether. Consequently, workforce in the coming

decades will require newer set of skills. Roehrig et al. (2012) claim that these changes in the professional ambit are placing increasing demands for individuals with expertise in STEM fields. The 2013 report from the Committee on STEM Education in the USA also reiterated this view adding that such expertise will be required by professionals working in non-STEM occupations as well (English, 2016). Consequently, STEM education is seen as an essential tool for helping students be ready for the competitive workforce in the 21st century (Lian et al., 2021). Given the rising dependency of occupations on STEM skills, it is no wonder then that countries with workforce skilled in STEM will have an edge in global competitiveness. This is perhaps reflected in widespread adoption of STEM education initiative in educational reforms around the world (Yanez et al., 2019).

Naturally, engagement of learners in STEM education in elementary schools has of late received considerable attention and interest. However, implementation of STEM education and engaging learners in STEM is anything but easy. Researchers have identified several challenges, including the necessity for integrated STEM instruction to involve students in addressing real-world problems (Sivaraj et al., 2020) and learners feeling that STEM subjects, in particular science and mathematics, are irrelevant to them due to their abstract nature (Tan et al., 2023). According to Sahin et al. (2014) such abstract nature of the two disciplines, seemingly unrelated to problems in the real world and learners' experiences can lead to decreased interest and motivation to engage with STEM on learners' part.

Several ways have been proposed to enhance student engagement in STEM disciplines, prominent among which is integrated STEM education which has the potential to improve students' motivation to learn STEM (Thibaut et al., 2018). The goal of the integrated STEM instruction is to provide students with a holistic understanding of the STEM disciplines. Other pedagogical approaches that have garnered attention are project-based learning (PBL), inquiry-based learning (IBL) and design-based learning (DBL). Although all three approaches have some commonality, each methodology has distinct starting points and can aid STEM instruction in different ways. PBL has been found to actively engage students in applying STEM knowledge in controlled environments (Movahedzadeh et al., 2012) by working collaboratively with peers and thus providing them with meaningful learning experiences (Hanif et al., 2019). IBL could improve students' learning achievement, satisfaction with the course, and attitude toward technology. Furthermore, IBL can facilitate the integration of STEM subjects (Deák et al., 2021). On the other hand, DBL appears to be effective in

enhancing STEM pedagogy by situating learning in real-world contexts to apply their knowledge (Kelley & Knowles, 2016), which in turn can boost their interest in learning STEM subjects and positively influence their perceptions of them.

Teachers, however, face a multitude of challenges in implementing such pedagogical approaches. Time constraints and lack of good resources, among others, are two of the most cited by teachers (Fitzgerald et al., 2019). While research has shown that these pedagogical models are very effective in enhancing student engagement, there remains need for developing specific instruction tools that lend themselves well to one or more of the pedagogical models.

This study investigates the potential of a novel design discipline known as 'Biomimicry' in engaging learners in a STEM classroom. Biomimicry, also known as biomimetics, in simplest terms is emulating various strategies evolved by natural organisms to find sustainable solutions to complex human problems (Benyus, 2002). It involves observing how certain organisms tackle certain challenges and adopting those solutions by designing systems that can be used by humans. For example, instead of using current energy-intensive systems of climate regulation, one might observe how termites regulate temperature inside termite mounds and designing buildings that try to emulate the design of termite mounds, thereby facilitating flow of air without any external control (Pearce, 2016; Tanyanyiwa & Juba, 2018).

Biomimicry is interdisciplinary. As biomimicry is fundamentally a nature-inspired design-discipline, it naturally involves natural sciences and engineering, two of the constituents of STEM. Engineering is a design discipline itself. As mathematics is inseparable from engineering design and production, and technology is the result of engineering, the other two constituents are also thus incorporated in biomimicry. Biomimicry thus seems to lend itself very well to STEM instruction. Biomimicry offers a novel approach to teaching STEM by supporting and developing science teachers (Vasinayanuwatana & Plianram, 2023). According to (Gencer et al., (2020) it inspires students across various age cohorts through integration, real-world problem-solving, design, and systems-thinking. Additionally, as biomimicry aims to develop sustainable solutions, it engages students by being agents of change in the world (Kelley et al., 2020).

1.1 Biomimicry

Biomimicry is a multidisciplinary design methodology which draws inspiration from nature to find solutions to challenges in the human world in a sustainable manner. Janine Benyus (2002) through her seminal work *Biomimicry: Innovation Inspired by Nature*, popularised the term Biomimicry. She defines it as "the conscious emulation of life's genius" (p. 2). The central premise of biomimicry is that nature, through 3.8 billion years of evolution, has already found solutions to many a problem humans face. Rather than viewing nature solely as a resource to be extracted, biomimicry encourages humans to perceive the natural world as a source of knowledge and innovation. Some prominent examples of successful implementation of biomimicry include kingfisher inspired redesigning of Japanese shinkansen (bullet train) to reduce aerodynamic drag, Velcro inspired by burrs, and mycelium inspired affordable, non-toxic building materials.

Benyus (2002) distinguishes three primary levels at which biomimicry operates: mimicking form and structure (e.g., the shape of a lotus leaf for self-cleaning surfaces), mimicking processes (e.g., photosynthesis for energy conversion), and mimicking whole systems (e.g., nutrient cycling in ecosystems for circular economies). Importantly, this approach is not the replication of aesthetic features but understanding and applying the underlying principles of natural designs and functions.

Effective practice of biomimicry demands a confluence of cognitive, technical, and ethical competencies, often spanning diverse disciplines. Firstly, ecological literacy and keen observational skills are fundamental. Practitioners must be able to identify functional strategies in biological systems and understand the ecological contexts in which these strategies have evolved. Additionally, creativity and iterative design thinking are crucial. Translating biological principles into human technologies involves abstraction, prototyping, and refinement, necessitating both divergent and convergent thinking skills. Biomimicry practitioners must also navigate interdisciplinary collaboration, working across professional domains such as biology, engineering, design, and sustainability science (Vincent et al., 2006).

1.2 Research questions

Plenty of research has been done on the use of biomimicry to develop certain skills in higher education institutes, mainly in design disciplines such as engineering, architecture, and even

product design. However, despite the potential of biomimicry as a STEM instruction tool, research on how it engages elementary school students is sparse. This study aims to investigate how implementing biomimicry lessons can engage students and thus aide in STEM instruction. Specifically, this study aims to investigate the following question:

- Does integration of biomimicry in STEM classroom affect student engagement in and their perceptions of STEM content and careers in STEM?

2 Literature Review

To be able to investigate the phenomenon of engagement in STEM learning and affect toward STEM learning and careers using biomimicry, this study tries to systematically review theories concerning student perceptions of STEM content and careers, integrated STEM framework, STEM pedagogies, and finally how biomimicry fits into the equation.

2.1 Integrated STEM

Various definitions and descriptions of what constitutes integrated STEM have been put forth by scholars. In their review of the literature on STEM education, Martín-Páez et al. (2019) define STEM education as "a teaching approach that integrates the content and skills specific to science, technology, engineering, and mathematics" (p. 815). Similarly, Moore et al. (2014) conceptualised STEM education as “an effort to combine some or all of the four disciplines of science, technology, engineering, and mathematics into one class, unit, or lesson that is based on the connections between the subjects and real-world problems” (p. 38). They go on to cite Smith and Karr-Kidwell (2000) in that integrated STEM education is “a holistic approach that links the disciplines, so the learning becomes connected, focused, meaningful, and relevant to learners” (p.22). Kelley and Knowles (2016) present a conceptual framework for integrated STEM education that underlines the incorporation of "STEM practices within an authentic context" (p. 3) to enhance student learning. Despite various definitions and differences in whether some or all of the constituent disciplines of STEM should be combined, all the definitions stress the significance of using real-world contexts to not only contextualise learning, but also to promote student engagement in learning of STEM subjects (Roehrig et al., 2021).

Roehrig et al. (2021) argue, however, that there is a lack of specific guidelines for implementing integrated STEM within classroom instruction or curricula. In the absence of clear recommendations regarding effective practices and strategies, educators may face challenges in designing and delivering integrated STEM lessons that successfully engage students in STEM learning. To tackle this problem, Roehrig et al. (2021) have proposed a conceptual framework for implementing and evaluating integrated STEM lessons. This study uses this framework which is henceforth referred to as iSTEM. The seven key components of this framework and their significance for student engagement are summarized below.

1. **Focus on Real-World Problems**: Integrated STEM instruction should prioritize authentic, real-world challenges that immerse students in meaningful and relevant learning experiences. Struyf et al. (2019) suggest that problem-centred learning in which authentic real-world problems are used as instructional material can make learning content more relevant for learners.
2. **Centrality of Engineering**: Engineering design should play a central role in integrated STEM education, allowing students to apply scientific and mathematical concepts to solve practical problems. Siverling et al., (2019) found that students used science and mathematics content in an integrated manner to create and justify their design ideas. Integrating engineering design is also found to have a positive effect on student engagement in STEM content (Tank et al., 2018).
3. **Context Integration**: The integration of STEM disciplines should be contextualized within the real-world problem being addressed, providing relevance and authenticity to the learning experience. A study by Burrows et al., (2013) demonstrated better knowledge gain and student engagement through the use of "Application, Career Connections, Societal Impact (ACS)" method which "relies on application of content through real-world experiences and lays a strong foundation for teaching abstract concepts and developing enhanced learning experiences through career connections and a focus on the impact on society (p.7)".
4. **Content Integration**: Interdisciplinary relations among STEM disciplines should be made clear to students, highlighting the interdisciplinary nature of problem-solving in STEM. Research suggests that when students are exposed to the interdisciplinary nature of STEM disciplines through content integration, it increases the likelihood of them being interested in STEM throughout their school years and of them choosing a STEM related career (Daugherty & Carter, 2018).
5. **STEM Practices**: Students should partake in authentic STEM practices, such as inquiry-based learning, problem-solving, and evidence-based reasoning, to develop critical thinking skills. Opportunities to engage in these practices can allow students to be active agents in the learning process (Bilici et al., 2021; Kelley & Knowles, 2016).
6. **Twenty-First Century Skills**: The goal of the integrated STEM education is to promote the development of key competencies, including creativity, collaboration, communication, and critical thinking, thereby preparing students to meet the demands of the contemporary workforce.

7. **Informing Students about STEM Careers**: Educators should expose students to various STEM career pathways, helping them understand the importance of STEM education in future opportunities for career.

2.2 Students' Perceptions of STEM content and careers

Perception of STEM content and careers can manifest among students in various ways. However, for the purposes of this study perception of STEM could be said to encompass the beliefs and opinions that students have toward the constituent disciplines of STEM and future careers. This text will mainly focus on negative perceptions of STEM subjects and careers. Such negative perceptions can include lack of interest in STEM learning, misconception about STEM fields, low self-efficacy in STEM subjects, among others.

Various studies have investigated the decline in students' interest in STEM disciplines. Kelley and Knowles (2016) found that there has been a decrease in students' motivation toward STEM learning in western countries, but also in some developed Asian countries. Limited public understanding, the devaluation of STEM fields, and pervasive apathy and underperformance in mathematics and science among students have been cited as cause of this decline in interest (Dong et al., 2020; Mohr-Schroeder et al., 2014). Factors including self-efficacy, previous academic performance, perceived difficulty, interest, gender stereotypes, and career aspirations have also been associated with this decline in interest (Holmes et al., 2022). Moreover, Krapp and Prenzel (2011) have pointed out the relationship between students' lack of interest and poor pedagogical practices, such as more teacher centric teaching involving more lecture styled lessons.

Additionally, STEM disciplines and careers are perceived as specialist and the domain of a few talented individuals. This likely stems from a lack of understanding of what STEM professions such as engineering involve (Yoon et al., 2014). Fixed-mindset beliefs such as success in STEM is due to innate abilities and intelligence have been demonstrated to negatively affect students' interest in STEM content and careers (Shin et al., 2016). Gender biases and negative stereotypes have also been shown to negatively influence students' interest in learning STEM disciplines and their motivation to pursue STEM careers (Handley et al., 2015; Machado-Casas et al., 2020). STEM fields may be perceived as male dominated, especially in engineering and computer sciences (Archer et al., 2018).

2.3 Student Engagement

Student engagement is a multidimensional and intricate concept that has been interpreted and defined in multiple ways. It encompasses behavioural, affective, and cognitive aspects of an individual. Fredricks et al. (2004) define student engagement as a multifaceted concept that includes three main types, which significantly influence school engagement (SE) in various ways (Martins et al., 2022). The engagement types and how they affect school engagement are described below.

Behavioral Engagement: This refers to students' positive conduct, such as following rules, attending school, and being involved in academic tasks such as effort, persistence, concentration, and participation in school-related activities (e.g., clubs or athletics) (Fredricks et al., 2004). Behavioral engagement addresses observable actions, such as participation in class and adherence to classroom rules. Students who are behaviorally engaged consistently attend classes, complete assignments, and participate in extracurricular activities. Studies have shown that a strong behavioral engagement often correlates with better academic outcomes and a more positive school experience (Martins et al., 2022).

Emotional Engagement: This encompasses students' emotional reactions to school, including their enjoyment, sense of belonging, and identification with the institution (Fredricks et al., 2004). Emotional engagement relates to students' affective reactions and their sense of connectedness to school. Positive emotions (e.g., happiness, calmness) can enhance students' interactions with peers and teachers, leading to higher levels of social-behavioral engagement. Conversely, negative emotions (e.g., sadness, anxiety) can result in disengagement, such as social loafing, where students exert less effort when working with others (Martins et al., 2022).

Cognitive Engagement: This involves the psychological investment in learning, including the use of self-regulated learning strategies, willingness to exert effort, and a preference for challenging tasks (Fredricks et al., 2004). Cognitive engagement involves students' investment in their learning, including their use of self-regulation and metacognitive strategies, problem-solving skills, and motivation. When students adopt effective learning strategies and perceive value in their academic tasks, they are more likely to overcome challenges and engage deeply with the material being learned. For instance, students who find mathematical tasks interesting are likely to display more effort and persistence, while those who feel pressured may experience anxiety, which can impede their engagement (Martins et al., 2022).

Active interest in Science, Technology, Engineering, and Mathematics (STEM) significantly influences students' views on both STEM education and career opportunities in these fields. Research highlights the strong link between engagement and increased interest and confidence in STEM careers, ultimately shaping students' career aspirations. Studies show that participation in STEM projects, especially those using PBL, enhances students' perceptions of STEM subjects. According to Kwon et al. (2021), despite the challenges within STEM disciplines, students who actively participated in STEM PBL activities developed a more positive view of mathematics and STEM careers. This suggests that experiential learning plays a key role in boosting students' interest and confidence in their abilities (Kwon et al., 2021). Middle school experiences are particularly influential, as attitudes formed during this period can impact academic performance and career choices. Christensen and Knezek (2016) emphasize the importance of understanding students' perceptions of STEM at this stage to support the development of a future STEM workforce. Early exposure to STEM activities, including hands-on learning and career exploration, can spark long-term interest in these fields. Wang et al., (2015) found that motivational factors are significant in shaping students' future aspirations in STEM. Research further reinforces the notion that hands-on experiences in informal learning environments have a positive effect on students' perceptions of STEM and enhance the possibility of pursuing STEM careers (Roberts et al., 2018). These settings allow students to apply theoretical knowledge in practical contexts, fostering a sustained interest in STEM subjects beyond the classroom.

2.4 Pedagogical Approaches

2.4.1 Project-Based Learning

Project-based pedagogy has emerged as a powerful approach to enhance student engagement in STEM disciplines. This approach promotes active learning by engaging students in hands-on experiences, enabling them to apply theoretical concepts to real-world challenges. Research indicates that PBL significantly boosts student motivation and interest in STEM fields by fostering a sense of ownership and relevance in their education (Peters-Burton et al., 2019). For instance, Peters-Burton et al. (2019) highlight that students engaged in STEM-focused environments develop a reflective attitude towards their learning, which enhances their understanding and interest in these subjects. Additionally, hands-on activities aid in enhancing students' interest in STEM and enhance the perceived utility of STEM education, making it more relevant to students' lives.

Moreover, PBL promotes collaboration and critical thinking, essential skills for success in STEM careers. Kelley and Knowles (2016) assert that teaching STEM concepts through project-based approaches allows for integrated learning experiences that connect various disciplines, thus preparing students for interdisciplinary work in their future careers. This integration is crucial as the modern workforce increasingly demands professionals who can navigate multiple fields and collaborate effectively. Furthermore, Morgan et al. (2018) observed that teachers reported higher levels of student engagement when employing PBL strategies, indicating that this pedagogical approach can considerably impact students' attitudes toward STEM subjects.

The principles of biomimicry align seamlessly with project-based learning, as both emphasize learning from nature to solve complex problems. Biomimicry encourages students to observe and emulate natural processes, fostering creativity and innovation in their projects. This approach enhances students' understanding of biological systems and encourages them to think critically about sustainability and environmental stewardship. For example, when students engage in projects that involve designing solutions inspired by nature, they develop a deeper appreciation for ecological principles and their applications in engineering and technology (Johnson et al., 2021).

Additionally, the interdisciplinary nature of biomimicry complements the project-based learning framework, allowing students to draw connections between biology, engineering, and environmental science. Such integration aids in cultivating 21st-century skills, like creativity, critical thinking, and collaboration, which are fundamental for achieving success in STEM fields (Mayes & Rittschof, 2021). By incorporating biomimicry into PBL, educators can create rich, engaging learning experiences that not only captivate students' interests but also prepare them for future challenges in STEM careers.

2.4.2 Inquiry-Based Learning

IBL is a pedagogical approach that places emphasis on active student participation, critical thinking, and the ability to draw conclusions from data (Minner et al., 2010). When applied in elementary schools, it can positively influence students' views of STEM subjects and careers. Through hands-on investigations, collaborative problem-solving, and discovery-based learning, IBL enhances students' grasp of STEM concepts and sparks a deeper interest in these fields (Verma & Ali, 2023).

Research shows that inquiry-based science instruction can positively affect students' attitudes towards STEM subjects (Riegle-Crumb et al., 2015). By actively engaging students in the learning process and encouraging independent exploration of scientific concepts, this approach promotes curiosity, engagement, and motivation among elementary students (Oppong-Nuako et al., 2015). It not only fosters a greater appreciation for STEM content but also helps develop critical thinking, creativity, and scientific inquiry skills (Toma & Greca, 2018).

IBL also significantly shapes students' perceptions of STEM careers by providing opportunities for real-world problem-solving and hands-on experimentation (Murphy et al., 2019). By empowering students to take ownership of their learning and explore STEM concepts in a meaningful way, this method can inspire them to consider STEM careers. Additionally, it aids students in developing essential skills, including communication, collaboration, and problem-solving, which are vital for success in STEM-related professions (Moote et al., 2013).

IBL is a pedagogical approach that can positively impact elementary students' perceptions of STEM content and careers. By fostering active engagement, critical thinking, and hands-on exploration, it enhances students' interest in STEM subjects, deepens their understanding of scientific concepts, and encourages them to pursue future opportunities in STEM fields.

2.4.3 Design-based learning

DBL is a method that incorporates design principles into the learning process, allowing students to participate in practical, creative problem-solving activities. When implemented in elementary schools, this approach can positively influence students' views of STEM subjects and careers. By integrating design aspects into STEM education, students are motivated to address real-world challenges, work together with peers, and use critical thinking to develop innovative solutions (Baker & Galanti, 2017). This method not only improves students' comprehension of STEM concepts but also cultivates a positive attitude towards these subjects (Perdana et al., 2021).

Studies have shown that DBL can augment elementary students' attitudes towards STEM by engaging them in project-based activities that are both relevant and meaningful (Ching et al., 2019). By embedding design principles into the curriculum, students can observe the practical applications of STEM concepts, which can increase their interest and motivation in these areas

(Gyasi et al., 2021). Furthermore, DBL helps students develop essential skills like creativity, collaboration, and problem-solving, which are vital for success in STEM-related careers (Perdana et al., 2021).

Additionally, the learning environment is essential in shaping students' perceptions of STEM. Research emphasizes the importance of creating engaging and interactive learning spaces that support DBL activities (Oliveras-Ortiz et al., 2021). By designing environments conducive to hands-on exploration and experimentation, educators can enhance students' learning experiences and foster a positive attitude toward STEM subjects.

DBL can significantly affect elementary students' perceptions of STEM content and careers by providing opportunities for hands-on, creative problem-solving activities, fostering a positive attitude towards STEM subjects, and developing essential 21st-century skills. By integrating design principles into the curriculum and creating engaging learning environments, educators can encourage students to pursue education and careers in STEM.

2.5 Biomimicry Integration and Finnish National Core Curriculum

Biomimicry aligns closely with the transversal competencies and subject-specific objectives outlined in the Finnish National Core Curriculum (NCC) (Finnish National Agency for Education [FNAE], 2016). The Finnish curriculum prioritizes the development of competencies, such as critical thinking, collaboration, and creativity, which equip students to navigate the complexities of the contemporary world. These competencies resonate with the core principles of biomimicry, which advocate for sustainable design and innovative problem-solving inspired by natural systems.

The Finnish National Core Curriculum (NCC) places strong emphasis on the development of transversal competencies, including collaboration, communication, and critical thinking, across various educational settings (Vitikka et al., 2016). Biomimicry naturally promotes collaborative learning, as students work together on design-based projects, analyzing and emulating natural systems to address human challenges. For example, students may engage in group projects to create solutions inspired by natural adaptations, drawing on ecosystems that have evolved efficient resource management strategies. This form of hands-on, project-based collaboration aligns closely with the NCC's objectives of cultivating essential future-oriented skills.

In addition, the NCC advocates for problem-solving and inquiry-based learning approaches, urging students to confront real-world challenges. Biomimicry complements this educational vision by encouraging students to explore natural phenomena and derive sustainable solutions (Fried et al., 2020). Through the study and application of biological principles to innovation, students not only deepen their understanding of ecological systems but also strengthen critical problem-solving skills (Linder & Huang, 2022). This inquiry-driven methodology is well-aligned with the NCC's emphasis on applying knowledge in practical and meaningful contexts.

Sustainability is also a central theme within the NCC, which aims to foster an understanding of ethical and ecological responsibility among students (Vitikka et al., 2016). Biomimicry directly supports this goal by promoting environmental awareness and sustainable practices. By examining how natural systems operate efficiently and applying these insights to sustainable design, students develop a commitment to environmental stewardship (Linder & Huang, 2022). In doing so, biomimicry not only advances the sustainability aims of the NCC but also equips students to actively contribute to the improvement of their communities and environments.

Moreover, the NCC emphasizes collaborative learning and interdisciplinary approaches, which are also inherent in biomimicry practices. The methodology encourages students to work together to explore and innovate, drawing from diverse fields such as biology, engineering, and design. This collaborative spirit is essential for addressing complex challenges, as seen in the case studies of urban infrastructure that utilize biomimetic designs to enhance functionality and sustainability (Buck, 2017). The curriculum's focus on transversal competencies, such as critical thinking and problem-solving, aligns with the innovative mindset required for biomimetic design, where students learn to analyse natural systems and apply those insights to human-made environments (Palsa & Mertala, 2019).

Furthermore, the Finnish curriculum's emphasis on creativity and innovation is mirrored in the principles of biomimicry, which advocate for a shift from conventional design thinking to more inventive approaches that prioritize ecological harmony (Faragalla & Asadi, 2022). This paradigm shift is crucial for developing solutions that are not only effective but also sustainable, as demonstrated by regenerative practices in agriculture that draw inspiration from natural processes (Gremmen, 2022). The curriculum's goal of nurturing creative and critical thinkers prepares students to engage with these innovative methodologies, fostering a generation capable of addressing the pressing environmental challenges of our time.

2.6 Biomimicry in teaching STEM

Biomimicry is an interdisciplinary approach which incorporates studying nature's principles and mechanisms to solve design challenges, with a strong emphasis on sustainability. The reductive view of biomimicry focuses on transferring biological technologies to engineering and design, whereas the holistic view aims to create ecologically sustainable products that are environmentally friendly throughout their lifecycle (Volstad & Boks, 2012). This dual perspective highlights biomimicry as both an inquiry-based process of examining nature's mechanisms and a design-based process of applying these insights to develop innovative solutions (Ilieva et al., 2022).

Incorporating biomimicry into educational lessons can positively impact students' perceptions of STEM subjects and careers. It provides an interdisciplinary approach that enables students to explore and apply nature's principles to solve design problems, emphasizing sustainability (Ilieva et al., 2022). This integration can transform education by inspiring students of all ages through a combination of life sciences, STEM subjects, creative problem-solving, design thinking, and systems thinking (Gencer et al., 2020). This method not only enhances students' understanding of STEM concepts but also deepens their appreciation for the interconnectedness of nature and technology.

Biomimicry in education can be implemented through two main design methodologies: problem-based and solution-based approaches (Othmani et al., 2022). The problem-based approach starts with a design challenge and seeks solutions in biology, while the solution-based approach begins by studying nature and then designing based on those biological principles. This dual approach reflects the inquiry-based and design-based nature of biomimicry, engaging students in creativity and critical thinking to solve real-world problems by emulating nature's strategies (Hassan et al., 2023).

Furthermore, as Gencer et al. (2020) have demonstrated, biomimicry can transform STEM pedagogy by providing teachers with a tool to motivate and engage students through the integration of life sciences, design thinking, and systems thinking. The authors suggest that by incorporating biomimicry principles into lessons, educators can encourage students to think innovatively, apply scientific concepts in practical contexts, and acquire a more profound

understanding of the natural world. This hands-on approach to learning not only improves academic performance of students but also nurtures a passion for STEM subjects and careers.

According to Kennedy (2017), incorporating biomimicry into STEM education helps students develop essential skills such as observation, creativity, critical thinking, and problem-solving. The author claims that engaging in activities that involve studying and emulating nature's designs encourages students to explore scientific concepts and principles more deeply. This approach enhances their understanding of STEM subjects and fosters a sense of curiosity and wonder about the natural world, leading to a more positive perception of STEM disciplines and potential career paths.

Additionally, biomimicry offers a unique tool for students to help them relate theoretical knowledge and practical application in STEM fields. By incorporating biomimicry principles into the design process, students gain hands-on experience in applying scientific concepts to real-world challenges, fostering a deeper understanding of how nature can inspire innovative solutions. This experiential learning approach enhances problem-solving skills, promotes environmental stewardship and sustainability practices in students' approach to STEM disciplines.

Biomimicry is a powerful tool in STEM education, offering students a unique opportunity to engage in inquiry-based and DBL simultaneously. By integrating biomimicry principles into educational lessons, students can develop essential skills, deepen their appreciation for STEM disciplines, and gain hands-on experience in applying scientific concepts to real-world challenges. This holistic approach enhances academic performance, in addition to fostering a passion for sustainability, innovation, and creativity in STEM disciplines and careers.

3 Methods

3.1 Research Design

This study employed a mixed methods approach to investigate how the integration of biomimicry in STEM classrooms affects student engagement and their perceptions of STEM learning and careers. The study employed quasi-experimental design using pretest-posttest control group design to reduce any internal threats (Fraenkel & Wallen, 2019). In addition to the quantitative data collected through pre and posttests, class observations and teacher interview provided qualitative data. By combining quantitative and qualitative data, this design aimed to provide a comprehensive understanding of the impact of biomimicry-focused lessons on fifth grade students.

3.2 Participants

Two groups of students of fifth grade from a Finnish comprehensive school located in Southwest Finland were selected to be participants in this study. One group was the control group (CG) whereas the other was an experimental group (EG). The criterion for the selection of the group was primarily familiarity of one of the class teachers with the author and their availability and willingness to participate in the study. The experimental group was selected for the treatment to be assigned based on their teachers' beliefs that the group had lower levels of engagement in STEM subjects compared to the other group. The total number of participants in this study were 26 fifth grade students, with 14 students in the control group and 12 students in the experimental group.

The class teacher of the treatment group was interviewed after the treatment phase. The teacher was a female teacher with about 10 years of teaching experience out of which she has been a class teacher for 7 years. Prior to the introduction session given to the teacher about biomimicry, she had no knowledge of biomimicry and had not used as a tool in any science lessons.

3.3 Data Collection

3.3.1 Classroom-observation Protocol

An observation protocol was developed by the author based on literature on behavioural, cognitive, and emotional engagement (Fredricks et al., 2004; Martins et al., 2022). The observations focused on the behavioural engagement as it is defined as encompassing observable actions and efforts of individuals in their learning environment. Indicators of behavioural engagement used by Lashari et al. (2013) were used to record engagement behaviours during all observation phases. These include indicators of Positive Behavioural Engagement and Negative Behavioural Engagement as shown in the Table 1 below.

Table 1: Behavioural engagement indicators

Positive Behavioural Engagement	**Negative Behavioural Engagement**
1. Asking questions voluntarily	1. Yawning / Sleeping / Sitting slouched
2. Responding voluntarily	2. Fiddling with objects
3. Interacting with classmates to complete task	3. Daydreaming / Looking into void / Not looking at the front
4. Completing homework / assignments on time	4. Disruptive behaviour (Talking with peers while teacher is talking / throwing objects at peers)
5. Looking at the teacher / at the SmartScreen / at the front	

Instances of occurrences of the above behaviours were recorded for various stages in each observed lesson.

3.3.2 STEM Semantics Survey

To collect quantitative data about students' engagement, STEM Semantics Survey designed by Tyler-Wood et al. (2010) was adopted. Permission was obtained from the authors via email to use the instrument, a screen capture of which can be found in Appendix 1.

The STEM Semantics Survey contains 25 Likert-scale type items that help measure student perceptions of science, technology, engineering, and mathematics in addition to interest in STEM careers in general. As the original survey is in English, it was translated into Finnish and

subsequently checked by the senior teacher who is the class-teacher of the control group. Additionally, the scale was changed from 7 points to 5 points to adjust for the comprehension level of 5th grade students. The instructions for completing the survey and some of the words were changed according to the class teacher's suggestions. The original and the translated survey can be found in Appendix 2a and Appendix 2b.

Tyler-Wood et al. (2010) reported that the internal consistency reliabilities on perceptions of science, math, engineering, technology, and STEM as a career varied between Alpha = .84 and Alpha = .93, ranging from "very good" to "excellent" in line with the guidelines suggested by De-Vellis (1991).

The internal consistency reliabilities for the combined sample (n = 26), as measure for the Pretreatment Survey 1, across perceptions of science, mathematics, engineering, technology, and STEM careers ranged from Alpha = .822 to Alpha = .897. According to DeVellis (1991), these values fall are considered "good". Table 2 presents the reliability scores for each scale.

Table 2: Cronbach's Alpha values for STEM Semantics Survey Scales

Scale	Number of Item	Alpha
Science	5	.831
Mathematics	5	.897
Engineering	5	.889
Technology	5	.892
STEM as Career	5	.822

3.3.3 Teacher Interview

After having obtained appropriate consent (Appendix 3) from the class teacher of the experimental group, a structured in-person interview was conducted with them to evaluate their perception of any changes in the behavioural engagement during and after the treatment. The interview was recorded and then transcribed verbatim.

3.3.4 Ethical Considerations

This study followed the ethical guidelines for research involving human participants, as established by the Finnish National Board on Research Integrity (TENK, 2019). The research was conducted in an elementary school in Southwest Finland and involved both minors and a teaching professional. Permission to carry out the study in the two classrooms was obtained from the school administration.

Participation was voluntary, and informed consent was obtained prior to data collection in line with Finnish ethical standards. For the student participants, written consent (Appendix 4) was sought and received from their parents or legal guardians. Fourteen students from the control group and twelve students from the treatment group participated with parental consent. The classroom teacher who participated in the post-intervention interview also provided written informed consent.

To protect the anonymity of the student participants, the classroom teacher assigned each participating student a unique identifier known only to them. The researcher did not have access to students' names or any personally identifiable information. Survey data were collected using paper forms, which were then digitized for analysis. Both the paper and digital versions of the surveys will be securely stored until the thesis is approved, after which they will be permanently destroyed.

The post-intervention teacher interview was audio recorded and transcribed digitally. Both the audio file and transcript will also be deleted upon the completion and approval of the thesis. All data were handled in a manner that ensured confidentiality and data protection in accordance with the General Data Protection Regulation (GDPR) and national data protection legislation.

No sensitive or potentially harmful questions were included in the surveys, observations, or interviews. The study posed minimal risk to participants and followed the principle of avoiding harm. Ethical integrity and respect for the autonomy, privacy, and welfare of all participants were maintained throughout the research process.

3.4 Procedure

The treatment was implemented only in the EG classroom, but the student survey was implemented in both EG and CG classrooms. The lessons in CG classrooms were not observed before or during the intervention at the EG classroom. The teacher in the CG classroom was not informed about biomimicry. The CG teacher continued with her regular teaching at the time of the intervention at the EG classroom.

3.4.1 Pre-Treatment Phase

Classroom Observations

Before the treatment was administered, I observed Ympäristöoppi (environmental studies) and matematiikka (mathematics) lessons in the experimental group for 9 school days. The reasons for class observations were two-pronged, to familiarize the students from both groups with the author for the purpose of reducing the 'observer effect' as well as to observe engagement behaviours exhibited by both the groups.

The number of lessons observed in the treatment group was as shown in Table 3 below.

Table 3: Number of lessons observed in the pre-treatment phase

Phase	Ympäristöoppi (Environmental Sciences)	Matematiikka (Mathematics)
Pre-intervention	2	7
During intervention	6	

Student Survey

The first administration of STEM Semantics Survey to both the groups was done 10 school days before the treatment was administered to assess students' initial perceptions of STEM content and careers. The second administration was done one day prior to the beginning of the treatment in the control group and to the experimental group on the same day the treatment began.

3.4.2 Treatment Phase

Biomimicry-integrated Lessons

The treatment consisted of a series of 6 ympäristöoppi (environmental sciences) lessons aimed at teaching principles of catapult. Owing to the autonomous working nature of Finnish teachers, the main responsibility for drawing lesson plans was left to the class teacher of the EG. A basic training for the class teacher included fundamentals of biomimicry with the following concepts.

1. What is Biomimicry? What Biomimicry is NOT?
2. Why do Biomimicry?
3. What do we mimic in nature? Three levels of Biomimicry: Form, Processes, and Systems
4. How do we do Biomimicry? Bottom-Up Approach (Nature to Design) and Top-Down Approach (Design requirement to Nature)

It was also communicated to the class teacher that it is important for lessons to include the following for them to be considered Biomimicry integrated lessons.

1. What is Biomimicry? What is it NOT?
2. Ethos of Biomimicry
3. 3 levels of Biomimicry
4. Some examples of Biomimicry that students can easily relate to. For example, Velcro or space exploration robots.
5. Integration of science, math, and engineering
6. Opportunity for students to find a solution to a given problem
7. Designing a solution and prototyping, possibly using easily available materials (group work)
8. Presenting their solutions

The language of instruction throughout the treatment phase was Finnish since that is the regular language of instruction for the ympäristöoppi (environmental sciences) lessons. The lessons were planned and implemented by the class-teacher after receiving a basic familiarisation training in biomimicry. Biomimicry principles and examples were integrated into the lessons. However, due to the novel nature of biomimicry and the class teacher's perception of the students' current preparedness, the biomimicry content was limited to a brief explanation of

what biomimicry is, various relatable examples of biomimicry such as shinkansen (bullet train) and examples relevant to the content of the unit, the catapults.

The goals of the six-lesson unit were as follows:

1. Explore the principles of physics related to catapults
2. Understand the concept of biomimicry and its significance in design and engineering
3. Design and build a functional catapult inspired by an organisms (e.g. grasshopper, springtails, Mantis Shrimp)
4. Analyse the effectiveness of catapult designs through testing and iteration

Accordingly, the following unit plans were developed by the teacher:

Lesson 1: Teacher introduced the task for the students to plan a catapult in groups of 3-4 students. A video (https://www.youtube.com/watch?v=IO2By-1D1Os) with catapults was shown for students to base their designs off. The goal of the task was to make a catapult that can throw a projectile as far as possible. The students were given materials (popsicle sticks, rubber bands, plastic spoons, and a projectile) to build their catapults. They were asked to make plans for building catapults in groups. Students started making their initial prototypes.

Lesson 2: The students continued working on improving their catapult designs. The teacher introduced the idea of biomimicry using a PowerPoint presentation in which examples such as a race car inspired by the sleek form of body of cheetah (see Figure 1) and shinkansen (bullet train) inspired by kingfisher (see Figure 2) were described.

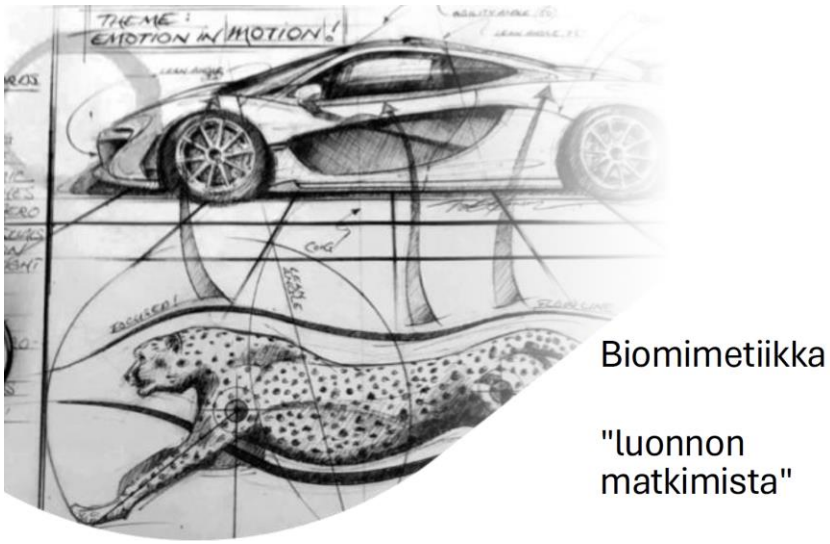


Figure 1. Race car design inspired by body of cheetah

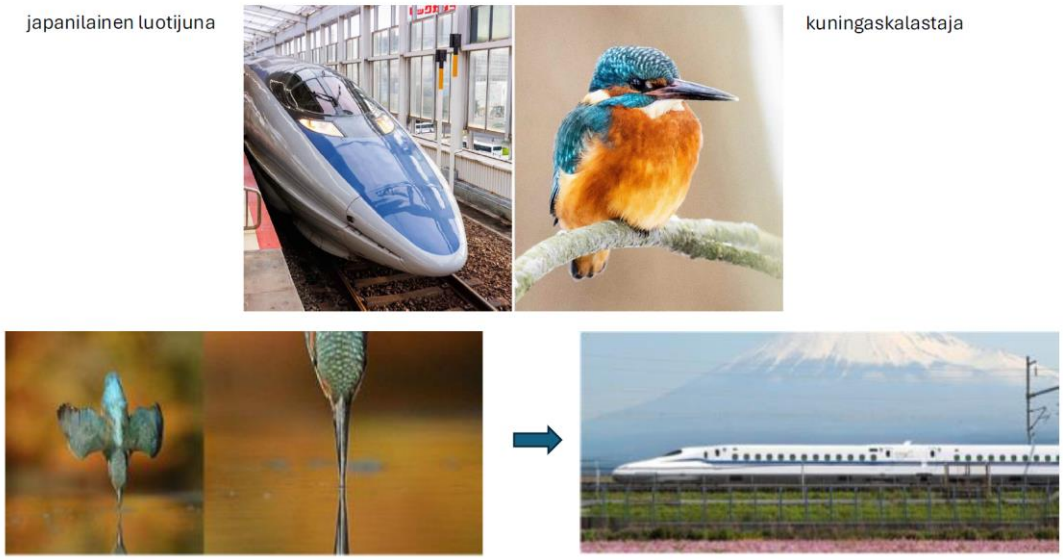


Figure 2. Japanese shinkansen (bullet train) inspired by kingfisher

Each group comprising of 3-4 students was given an A3 sized copy of an example of biomimicry, such as material surfaces inspired by germ resistant shark skin, wind turbines inspired by humpback whales' pectoral fins, and maple seed pods known as samaras, however without revealing the technological invention. The students were asked to read the text and discuss in groups which inventions might have been inspired by the organisms. After discussing in their own groups, students were asked to explain their biomimicry example to other groups. At the end of the lesson, the teacher asked the students to share what they had learnt about biomimicry and in which other ways natural phenomenon could be used to solve a technological problem.

Lesson 3: The teacher began by asking the students about problems they had encountered during the first iteration of their catapult designs. After the students had described any problems they had encountered, the teacher reintroduced the idea of looking at nature to see how nature solves problems. The teacher showed a video of springtails (https://www.youtube.com/watch?v=7_ZSTRDbJtc) and grasshoppers and elicited responses from the students about what they noticed about the mechanisms employed by the two organisms which are similar to catapults. The teacher, furthermore, showed animation (https://www.st-andrews.ac.uk/~wjh/jumping/jump-routine.html) illustrating the problem of building up enough force to be able to launch the organism or a projectile in the shortest amount of time and how grasshopper solves this problem by employing a energy storing device in its knees. The students were then asked to begin their task on improving their initial catapult designs.

Lesson 4: The teacher started the lesson by asking the students about their progress on catapult designs in the previous lesson. The teacher then elicited responses to questions to better explain concepts behind catapult mechanisms. The students then continued to work on their catapults, testing their designs from time to time.

Lesson 5: The students continued improving their catapults. The teacher instructed the students to now maintain a written record of the length of three projectile launches by the catapults designed by the students. At the end of the lesson, the whole class gathered together to present the catapults and test them.

Lesson 6: The teacher asked the students to reflect in groups on their catapult design and building process, how well they worked, and what the students could have done better. At the end of the lesson, students shared their reflections with the whole class.

Classroom Observations

During the treatment, systematic observations were conducted to monitor student engagement and participation. An observation protocol (see Appendix 3) was used to record students' interactions, enthusiasm, and involvement in the lessons. Specific attention was given to instances where biomimicry concepts appeared to enhance or hinder engagement.

3.4.3 Post-Treatment Phase

Student Survey

Following the treatment, STEM Semantics Survey administered in the pre-treatment phase was given to the students to evaluate any changes in their perceptions of STEM content and careers. This post-treatment survey aimed to measure shifts in interest, understanding, and perceptions of STEM. One survey was administered immediately on the same day that the treatment ended, while one more survey was administered 2 weeks later.

Teacher Interview

An interview with the class teacher of the treatment group was conducted to validate and provide further insights into the findings from class observations and the student surveys. This interview focused on any observed changes in student engagement and perceptions of STEM as a result of the biomimicry lessons. The interview was transcribed verbatim.

3.5 Data Analysis

3.5.1 Quantitative Analysis

The purpose of this quantitative analysis was to examine the effects of a biomimicry integration in environmental sciences (ympäristöoppi) lesson on 5th-grade students' overall perceptions of STEM (Science, Technology, Engineering, and Mathematics). A quasi-experimental pretest-posttest control group design was employed to measure attitudinal changes over time and between groups. The hypothesis was that the biomimicry integration would result in change in perception of the students from the EG whereas there would be no effect on the perceptions of the students from the CG.

The study utilized a 25-item Likert-scale survey administered at four time points: two pretests (Pretest1, Pretest2) and two posttests (Posttest1, Posttest2). The items represented students' general perceptions of STEM, and a composite mean score was calculated for each survey administration. Reliability analysis was conducted to ensure internal consistency, with results indicating high reliability. To evaluate the effect of the intervention, the analysis followed a multi-step approach:

1. **Assumption Testing:**
   Normality of the STEM perception scores was tested with the Shapiro-Wilk test, and homogeneity of variances with Levene's test. These were necessary to determine whether parametric tests (t-tests) were appropriate.
2. **Baseline Comparison:**
   Independent samples t-tests were conducted at Pretest1 and Pretest2 to verify whether the treatment and control groups were statistically equivalent in their perceptions before the intervention began. This helped establish the validity of comparing post-intervention outcomes.
3. **Within-Group Analysis:**
   Paired samples t-tests were used to examine changes in STEM perceptions within each group from Pretest1 to Posttest2. This tested whether students' perceptions improved significantly over time, particularly for the EG.
4. **Between-Group Comparison:**
   An independent samples t-test at Posttest2 was conducted to determine whether the EG had significantly higher STEM perception scores compared to the control group after the intervention.

To examine 5th-grade students' overall perceptions of STEM, a composite mean score was calculated from 25 Likert-scale items (1 = Strongly Disagree, 5 = Strongly Agree). Reverse-coded items were appropriately recoded prior to analysis.

The assumption of normality was tested using the Shapiro-Wilk test for all four time points (Pretest1, Pretest2, Posttest1, and Posttest2). Results indicated the distribution of the overall STEM perception scores did not significantly deviate from normality as shown in Table 4.

Table 4: Tests of normality.

	Shapiro-Wilk		
	Statistic	df	Sig.
Pretest1: Mean	,940	20	,243
Pretest2: Mean	,972	20	,798
Posttest1: Mean	,975	20	,858
Posttest2: Mean	,957	20	,492

As all *p*-values were above .05, the normality assumption was met, supporting the use of parametric tests in subsequent analyses.

Entries in the classroom behaviour observation protocol were counted for frequency. The frequencies of student behaviour types before and during the intervention was compared descriptively.

3.5.2 Qualitative Analysis

The qualitative data from notes from class observations and teacher interviews were analysed thematically. Coding was performed to identify recurring themes and patterns related to student engagement and perceptions of STEM. This analysis provided a deeper understanding of the nuances in student perceptions and the contextual factors influencing their perceptions.

To analyse the teacher interview, a coding scheme based on the literature on behavioural engagement (Fredriks et al., 2004; Martins et al., 2021) was designed, to identify ‘positive behavioural engagement’ and ‘negative behavioural engagement’. Furthermore, codes to identify ‘student interest’, ‘type of pedagogy / pedagogical method’ were added to the scheme to find any relationship between ‘behavioural engagement’ and ‘student interest’, and / or ‘type of pedagogy / pedagogical method’. After having developed the coding scheme, the teacher interview transcript was colour coded with each code, ‘Positive Behavioural Engagement’, ‘Negative Behavioural Engagement’, and ‘Type of Pedagogy’ being colour coded with a different colour. Finally, instances of each code were manually calculated.

4 Findings

4.1 The results of the t-tests

Independent samples *t*-tests were conducted to compare overall STEM perception scores between the CG (n = 14) and the EG (n = 12) at all time points Pretest1, Pretest2, Posttest1, and Posttest2.

For the Pretest1, the results indicated no statistically significant difference between the control group (M = 2.94, SD = 0.73) and the EG (M = 2.65, SD = 0.58); $t(24) = 1.11$, $p = .280$, Cohen's $d = 0.67$. Although the result was not statistically significant, the effect size suggests a possible moderate difference in baseline perceptions favouring the CG. For the Pretest2, the analysis revealed no statistically significant difference between the CG (M = 2.95, SD = 0.62) and the EG (M = 2.61, SD = 0.46); $t(23) = 1.52$, $p = .141$, Cohen's $d = 0.55$. Although the difference was not statistically significant, the moderate effect size suggests a possibility of meaningful difference in initial perceptions that may require further investigation. For Posttest2, the analysis indicated no statistically significant difference between the CG (M = 2.99, SD = 0.81) and the EG (M = 2.63, SD = 0.35); $t(20) = 1.33$, $p = .199$, Cohen's $d = 0.63$. Although the difference was not statistically significant, the moderate effect size suggests a possible meaningful difference in perceptions favouring the CG at this stage. Lastly for Posttest4, the results revealed a statistically significant difference in scores between the CG (M = 3.01, SD = 0.70) and the EG (M = 2.48, SD = 0.36); $t(22) = 2.27$, $p = .033$, Cohen's $d = 0.57$. This indicates a moderate effect size, suggesting that the CG reported more positive perceptions of STEM at this time point.

Further, a paired samples *t*-test was conducted to compare overall STEM perception scores between Pretest2 and Posttest1 in the EG (n = 10) to find any significant change in student perceptions from the first implementation of the instrument (2 weeks before the commencement of the treatment) to the last implementation (2 weeks after the end of the treatment). The results showed no statistically significant difference between scores at Pretest2 (M = 2.64) and Posttest1 (M = 2.59); $t(9) = 0.80$, $p = .445$, Cohen's $d = 0.23$. This small effect size suggests a negligible change in students' STEM perceptions following the intervention during this period.

Similarly, a paired samples *t*-test was conducted for the CG (n = 11) also to compare overall STEM perception scores between Pretest2 (one day before the commencement of the treatment) and Posttest1 (on the day the treatment ended). The analysis indicated no statistically significant difference between Pretest2 (M = 3.03) and Posttest1 (M = 2.99); $t(10) = 0.35$, p = .734, Cohen's d = 0.41. This result suggests that students' perceptions of STEM remained relatively stable over this period, with a small to moderate effect size that was not statistically significant.

4.2 Results of the observations

The analysis of observation protocol entries revealed changes in the frequency of positive and negative behaviours. Some positive behavioural engagement indicators, such as 'being attentive' and 'task focus and completion', during the intervention showed increase as compared to pre-intervention even though number of lessons observed during intervention was smaller than that of pre-intervention. However, the number of all negative behavioural engagement during the intervention also increased substantially. For example, 'daydreaming' which was observed only 2 times during the pre-intervention increased to 12 during the intervention. Similarly, 'disruptive behaviour' and 'distracted behaviour' also increased significantly as can be seen in Table 5 below.

Table 5: Frequencies of Behavioural engagement indicators

	Indicator Type	Pre-intervention	During-intervention
Total Number of Lessons Observed		9	6
Positive Behavioural Engagement Indicators	Asking questions voluntarily	2	1
	Responding voluntarily	9	7
	Task focus and completion	7	9
	Completing assignments	0	0
	Being attentive	6	16
Negative Behavioural Engagement Indicators	Disruptive behaviour	13	19
	Distracted behaviour / Fiddling with objects	15	21
	Daydreaming	2	12
	Yawning / Sleeping	0	1

The pre-intervention observations revealed a mixed pattern of student engagement, with both positive and negative behaviours occurring across lessons. Positive behaviours were generally seen during structured activities such as homework checking, teacher-led instruction, and individual problem-solving. Students often raised their hands to answer questions and were observed focusing quietly during tasks. For instance, in multiple lessons, students were noted as "focused on the task" and "solving problems quietly," and some demonstrated initiative by "asking for help" or "checking answers on their own."

However, these episodes of engagement were frequently punctuated by negative behaviours, which appeared in various forms across almost all pre-intervention lessons. These included off-task and disruptive behaviours such as playing or fiddling with objects, making noises, throwing items, talking across desks, and copying answers. In several cases, students were described as "passively participating" or showing "indifferent" engagement, especially during teacher explanations or whole-class work. For example, during a math lesson, students were "listening but not looking at the teacher," suggesting surface-level compliance rather than active cognitive engagement. In another instance, most students were "not focused on the task," requiring repeated instructions from the teacher. Even when students complied with directions, their attention sometimes waned quickly, and distraction was a recurring issue.

The intervention period, which consisted of a project-based unit on building catapults, demonstrated a shift toward more active and authentic engagement, although some challenges persisted. Students were generally more involved in the hands-on, collaborative activities. They discussed design changes, tested their prototypes, and some groups were noted for their critical thinking in improving their models. "Ss work actively on their prototypes," and "show keenness in testing their designs," indicated high levels of engagement. In at least two groups, "all members… were contributing," and some student designs clearly reflected their understanding of scientific principles, suggesting deep learning and applied comprehension. During the lessons when biomimicry was introduced, at least one student who had a tendency to 'daydream' or prone to showing 'distracted behaviour' was observed to be paying attention to teacher and responding voluntarily.

Despite these positive developments, engagement remained uneven. Some students were still passively involved or disengaged. In multiple cases, students were observed to be "not paying

attention" during presentations or teacher explanations, or as working on unrelated tasks such as drawing. The reflection and self-assessment task especially revealed variance in engagement. One group completed the task thoughtfully, discussing and responding in detail, whereas others appeared unclear about the expectations, copied answers, or completed the task with minimal effort. While students were "keen to present their designs," their attention waned when listening to peers, indicating a selective form of engagement more closely tied to personal involvement than community learning.

The contrast between the two observation periods may suggest that hands-on, inquiry-based instruction has the potential to promote greater engagement, particularly among students who may have previously struggled to remain attentive in conventional lesson formats. The physical construction of catapults, opportunities for peer collaboration, and the tangible outcomes of their work appeared to be promising to motivate students who had previously been passive or distractive. However, even within this more engaging context, challenges such as unequal participation within groups, superficial task completion, and limited attentiveness during theoretical or reflective moments persisted.

4.3 Findings of the interview

The teacher interview provided insight into student engagement behaviours during the science unit that included hands-on and inquiry-based learning activities. Central to this unit was a project involving the construction of catapults, along with an introduction to the concept of biomimicry and examples of catapults found in nature. The teacher described several examples of both positive and negative engagement behaviours, many of which reflected students' responses to the design of the learning activities and their own interests.

Students demonstrated their interest by paying close attention, asking questions, and becoming actively involved in class activities. During the catapult-building project, several students who were normally less participative became notably enthusiastic. The teacher remarked, "some of them didn't want to stop doing what they were doing with the catapults, because they were so interested in it." Some students also demonstrated engagement through extended learning beyond classroom expectations. One student, for instance, explored the topic further on her own time: "one of them was so excited about the topic that she had actually searched more information about it during the weekend, even though it was not a homework." Furthermore,

many students worked independently and stayed focused on the task, as the teacher described: “mostly they were really like independently working on the task and mostly also focusing on it and not something else.”

Biomimicry, though only briefly incorporated into the lessons, elicited a mix of engagement responses. The teacher observed that “some of the students did get the idea and when we kind of got back to it again, they remembered the examples that I showed them and so on.” This suggests a degree of cognitive engagement and retention of conceptual material. However, she also acknowledged that the biomimicry examples used—particularly the link between grasshopper mechanisms and catapults—may not have been meaningful to all students: “I think that maybe wasn’t too strong for some of them, the relationship.” While this does not constitute overt negative behaviour, it implies a possible gap in conceptual connection or clarity that may have limited deeper engagement for some learners. The teacher speculated that the inclusion of more concrete, hands-on biomimicry examples, like Velcro, might have made the concept more accessible.

Negative engagement behaviours were also mentioned, though less frequently. A key challenge arose when students were asked to transition from practical work to theoretical discussion. As the teacher noted, “they were so interested or so excited about the building part and the designing part that then when we had to like stop that and go to the theory part… they couldn’t really move to the next session.” This indicates a decline in engagement during more abstract, less tangible phases of the lesson. Additionally, some students experienced frustration due to performance comparisons. Although the activity was not intended to be competitive, the teacher remarked, “some of them probably were motivated about the idea that it’s a competition… and then it was also frustrating for them because some of the catapult was throwing the ball longer than theirs.”

The teacher identified several factors that shaped these engagement behaviours. The most prominent was the hands-on, exploratory nature of the activity. She explained, “probably because it’s fun to build something and it’s kind of playing. And they also can see the immediate results in action, which they cannot see on paper.” This immediacy of outcome seemed to reinforce the relevance of the learning experience. Collaborative work also contributed positively; students appeared motivated by group interactions and the social dimensions of the task. Interestingly, the teacher observed that some high-achieving students

who typically perform well in structured academic settings struggled with the creative and open-ended nature of the project. “They probably are the ones who want the right answers,” she suggested, “and they’re not that used to experimenting themselves or creating something new in science.”

5 Discussion

This study explored the impact of integrating biomimicry into STEM instruction on fifth-grade students' engagement and perceptions of STEM learning and careers with the aim of investigating if integration of biomimicry in STEM classroom affects student engagement and their perceptions of STEM learning and careers in STEM. The findings, situated within the frameworks of integrated STEM education and student engagement theory, suggest a nuanced effect of biomimicry integration, shaped by the nature of the instructional design and the contextual constraints of implementation.

The literature has consistently demonstrated that integrated and contextually relevant STEM instruction can enhance student engagement, particularly when framed within real-world, interdisciplinary problem-solving contexts (Kelley & Knowles, 2016; Roehrig et al., 2021). In line with this, the biomimicry-integrated lessons in the present study leveraged principles of project-based and inquiry-based learning. The findings from classroom observations and teacher interviews showed a marked increase in positive behavioural engagement, such as voluntary participation and sustained focus during the hands-on design and testing phases of the catapult project. These outcomes resonate with previous research indicating that experiential learning activities can elicit deeper cognitive and emotional investment from students (Fredricks et al., 2004; Kwon et al., 2021).

Notably, students who were typically disengaged in conventional instructional settings appeared more motivated during the intervention. The teacher interview corroborated this shift, noting students' sustained interest and even voluntary extension of learning beyond classroom requirements. Such behaviours align with the concept of "agentic engagement," whereby learners take initiative in directing their own learning (Reeve & Tseng, 2011) and provide promising evidence for biomimicry's potential in cultivating deeper engagement. However, the interpretations from the observations were limited in the sense that the duration of the intervention was short and this was the first time the students were involved in a biomimicry-integrated lesson. It can be speculated that longer involvement in such a lesson may result in more interest among the students.

Despite observable behavioural engagement during lessons, the quantitative findings from the STEM Semantics Survey did not show statistically significant improvements in students'

perceptions of STEM or careers in STEM. In fact, at Posttest2, the CG displayed slightly more positive perceptions compared to the EG. This outcome diverges from expectations based on prior studies (Ching et al., 2019; Roberts et al., 2018) and warrants critical reflection.
Several possible explanations emerge. Although the unit included elements of PBL and DBL, the limited duration of the biomimicry-integrated intervention may have been insufficient to effect measurable attitudinal change, especially considering the abstract and novel nature of biomimicry for both students and the teacher. Studies on attitudinal change emphasize the importance of sustained exposure and reinforcement over time (Krapp & Prenzel, 2011; Wang et al., 2015). Second, the degree of conceptual integration of biomimicry may have been superficial. While the design task itself was engaging, students may not have fully grasped the connection between biological principles and technological solutions, as suggested by the teacher's comment that the link between grasshopper mechanisms and catapults "wasn't too strong for some of them."
Furthermore, it is possible that the instrumentation—a translated version of the STEM Semantics Survey—may have lacked sensitivity to capture nuanced shifts in perception, particularly in a non-native language context. This reinforces the need for contextually validated instruments when conducting cross-cultural educational research.

The findings illustrate a tension between behavioural engagement and cognitive or conceptual understanding. While students were enthusiastic and actively involved during the building and testing of catapults, their engagement waned during reflective or theoretical discussions. This aligns with prior literature noting that hands-on activities must be carefully scaffolded to support transfer to abstract understanding (Mohr-Schroeder et al., 2014; Perdana et al., 2021). The teacher's reflection that "they couldn't really move to the next session" after the excitement of building indicates a need to develop pedagogical strategies that bridge physical experimentation with abstract reasoning.

This highlights an important implication: engagement alone may not be sufficient to shift perceptions unless it is accompanied by instructional strategies that promote metacognition, conceptual clarity, and career awareness. While the novelty of biomimicry captured students' attention, deeper impacts on perception may require more deliberate career integration, sustained application, and reflection on how STEM knowledge translates to real-world roles.

The results suggest that biomimicry holds potential as a design framework for engaging students in interdisciplinary, real-world STEM challenges. However, its impact on students' perceptions of STEM and future careers depends on how deeply and consistently it is integrated into instruction. Future implementations could include:

1. More extended units allowing sustained exploration of biomimicry concepts.
2. Explicit connections to STEM career pathways, possibly through guest speakers, career-oriented tasks, or virtual field trips.
3. Deeper scaffolding to support understanding of the scientific principles underlying the biomimetic designs.

One of the critical insights emerging from this study is the central role of teachers in effectively implementing biomimicry-integrated STEM instruction. As observed during the intervention, the depth and clarity with which biomimicry concepts were conveyed were limited by the teacher's own familiarity and confidence with the subject. Although the teacher received an introductory training on biomimicry, the novelty of the topic and the teacher's limited prior exposure constrained the extent to which deeper conceptual integration and student inquiry could be fostered. This highlights a pressing need for robust and ongoing professional development (PD) for educators, specifically designed to support interdisciplinary and innovative approaches such as biomimicry.

The findings align with broader research indicating that effective implementation of integrated STEM pedagogies requires targeted teacher preparation and support. Fitzgerald et al. (2019) report that time constraints and a lack of resources are frequently cited barriers by teachers attempting to adopt inquiry- and project-based STEM approaches. These challenges are magnified when teachers are expected to incorporate complex, interdisciplinary frameworks like biomimicry, which demand not only content knowledge across multiple disciplines but also pedagogical strategies that promote student-led inquiry, real-world problem-solving, and sustainability thinking.

Moreover, Kelley et al. (2020) emphasize that professional learning communities can enhance teachers' self-efficacy for integrated STEM instruction by fostering collaboration, reflective practice, and shared innovation. Their study found that when teachers were supported through collaborative PD environments, their capacity to design and implement interdisciplinary STEM

lessons improved significantly. Such findings suggest that teacher PD in biomimicry should not be limited to brief introductory sessions, but should instead be embedded within sustained, practice-based learning models that include co-planning, co-teaching, and reflective dialogue.

Given that the Finnish National Core Curriculum advocates for interdisciplinary, sustainable, and collaborative learning (FNAE, 2016), it is essential that teachers are equipped to translate these curricular goals into classroom practices. Biomimicry aligns well with these aims, but without appropriate training, teachers may struggle to move beyond superficial treatment of the content. As noted in this study, even a motivated and experienced teacher faced challenges in making meaningful connections between biological models and engineering principles—a gap that could be narrowed through scaffolded PD incorporating both theoretical understanding and practical classroom strategies.
Professional development for biomimicry in STEM should thus encompass:

1. Content knowledge in biomimicry and relevant STEM domains,
2. Pedagogical strategies that align with PBL (Morgan et al., 2018; Peters-Burton et al., 2019), IBL (Murphy et al., 2019; Oppong-Nuako et al., 2015; Riegle-Crumb et al., 2015; Verma & Ali, 2023) and DBL (Ching et al., 2019; Gyasi et al., 2021; Perdana et al., 2021),
3. Opportunities for collaboration and lesson co-construction with peers,
4. Reflective sessions to evaluate student engagement and learning outcomes.

With the help of such comprehensive support teachers can design learning experiences that fully leverage the transformative potential of biomimicry—not merely as an add-on topic but as a meaningful framework for interdisciplinary STEM learning.

In addition to professional development for teachers, the potential benefits of partnering with industry professionals could enhance the authenticity and relevance of biomimicry-integrated STEM instruction. One of the recurring themes in both the literature and the findings is the importance of making STEM learning meaningful by connecting it to real-world applications (Roehrig et al., 2021; Struyf et al., 2019). However, classroom teachers—particularly at the primary level—may not have extensive experience in translating cutting-edge biomimicry research or design practices into age-appropriate instruction. Collaborations with industry professionals, such as bioengineers, product designers, sustainability consultants, or architects

working with biomimicry, could provide much-needed content expertise and real-world context.

Such partnerships can play several important roles. First, they can support teachers in planning and delivering lessons that are grounded in current scientific and design practices. As highlighted by Kelley and Knowles (2016), a key element of effective integrated STEM education is the incorporation of "authentic contexts" that enable students to grasp the relevance of the material they are studying. Guest lectures, virtual tours of design labs, and live Q&A sessions with practitioners can bring a sense of realism and excitement that textbook-based learning may lack. These experiences help bridge the gap between abstract concepts and practical application, enhancing both cognitive engagement and career awareness among students.

Second, industry partnerships can serve as career exploration opportunities for students. Research has shown that students' perceptions of STEM careers are often limited or shaped by stereotypes, and that early exposure to diverse and relatable role models in STEM can broaden their aspirations (Christensen & Knezek, 2016; Handley et al., 2015). Inviting professionals who apply biomimicry in various fields—ranging from transportation to materials science—can demystify what STEM careers look like and demonstrate how creativity, sustainability, and scientific thinking are integrated in real-world problem-solving. These connections are especially critical in primary education, where foundational perceptions of STEM are still forming (Wang et al., 2015).

Moreover, such collaborations can support project-based learning by providing authentic challenges for students to work on, perhaps even co-developed with industry input. For example, a class project could revolve around designing a water-saving irrigation system inspired by desert plants, with feedback from a biomimetic engineer. These co-constructed experiences can cultivate not only technical understanding but also a sense of purpose and agency—key drivers of long-term engagement.

Finally, involving professionals in the classroom can contribute to teacher development, as educators gain insights into how biomimicry is applied in industry and how to effectively translate these insights for educational purposes. This dual impact—on students and teachers—

makes partnerships a highly strategic complement to more formal professional development structures.

In sum, fostering partnerships with industry professionals working in biomimicry-related fields offers a powerful, underutilized avenue for enriching STEM education. When combined with sustained teacher training, such collaborations can significantly strengthen the pedagogical and conceptual foundations necessary to implement biomimicry not merely as a novel topic, but as a deeply interdisciplinary and future-oriented approach to STEM learning.

6 Conclusion

This study has explored the pedagogical potential of biomimicry as means to enhance student engagement and foster more meaningful perceptions of STEM learning and careers. The findings suggest that even limited exposure to biomimicry within a hands-on, design-oriented learning context has the potential to elicit heightened behavioural engagement among students, particularly those previously disengaged. However, the results also indicate that short-term interventions are unlikely to yield significant shifts in students' broader perceptions of STEM without more sustained, conceptually integrated, and career-relevant instruction.

From a pedagogical perspective, biomimicry should not be treated merely as an engaging topic or occasional enrichment activity. Rather, its full educational potential lies in its adoption as a design and inquiry framework that fosters interdisciplinary thinking, problem-solving, and sustainability-oriented innovation. Teaching biomimicry should involve more than the presentation of biological analogies or surface-level examples. It should include structured opportunities for students to investigate how nature solves functional challenges, abstract principles from those solutions, and iteratively prototype and refine designs inspired by them. This necessitates a teaching approach that is inquiry-based, iterative, collaborative, and deeply contextualised in real-world problems—aligning closely with both the goals of integrated STEM education and the competencies outlined in national curricula such as Finland's.

Teachers must be adequately prepared and supported. Teachers' familiarity with and confidence in biomimicry might directly influence the depth of student learning. Therefore, increasing teachers' interest and competence in biomimicry requires not only access to conceptual training, but also training in pedagogical strategies for facilitating student-led exploration and integrating STEM content meaningfully. Professional development programmes should go beyond one-time introductory sessions and instead provide sustained, practice-based support. This can include opportunities for co-designing biomimicry lessons, engaging in interdisciplinary collaboration, participating in reflective dialogues, and interacting with industry professionals who apply biomimicry in real-world contexts.

Teacher education programmes can also play a pivotal role. Pre-service and in-service teacher education should incorporate biomimicry as one of the tools for interdisciplinary STEM integration. Integrating biomimicry into initial teacher education also offers a unique

opportunity to cultivate an inquiry-oriented professional identity among future teachers, which aligns with the broader aims of 21st-century education.

These findings suggest that while biomimicry holds promise as an engaging pedagogical tool, its transformative potential depends on more sustained, intentional integration. To influence student perceptions more meaningfully, biomimicry-based units should be longer, better scaffolded, and linked explicitly to real-world STEM careers and challenges. Further, teacher training in biomimicry pedagogy is essential to ensure fidelity of implementation and to enable deeper exploration of its interdisciplinary nature.

This research contributes to the emerging field of biomimicry in elementary STEM education by highlighting both its affordances and its limitations. It reinforces the idea that engagement is a necessary but not sufficient condition for shaping students' long-term perceptions of STEM. For biomimicry to fulfil its potential in inspiring the next generation of innovators, it must be embedded within pedagogies that foster not only active participation but also critical reflection, career relevance, and conceptual understanding.

Future research should expand on this work by involving larger and more diverse student samples, extending the duration of interventions, and developing contextually appropriate measurement tools. A deeper examination of the links between engagement types—behavioural, cognitive, and emotional—and student perceptions of STEM will be essential for advancing both the theory and practice of biomimicry-integrated STEM education.

6.1 Implications for my future career

Writing this thesis, from reviewing the literature to designing the experiment and the findings from the study, have consolidated my belief in interdisciplinary pedagogy. More and more research suggests integrating various subjects instead of traditional methods where subjects were taught as separate entities. As a future educator, I would endeavour to adopt such multidisciplinary and interdisciplinary pedagogy and include innovative disciplines such as biomimicry in my teaching. However, the study has also opened my eyes to the fact that any novel changes in established routines, however promising, must be based in solid evidence-based research and must go through rigorous and critical planning, implementation, and reflection. As a researcher, I might pursue the same topic further with improved experimental design and better planning.

7 Limitations

Several limitations should be acknowledged when interpreting the findings of this study. Firstly, the duration of the biomimicry-integrated instructional unit was relatively short. Given the complexity and interdisciplinary nature of biomimicry, a brief exposure may not have provided students with sufficient time to meaningfully engage with the concepts or to see their relevance to real-world STEM problems and careers. Additionally, the level of integration of biomimicry into the STEM lessons was introductory and limited in scope as biomimicry was a completely novel concept for both the teacher and the students and also because lesson planning was mainly done at the classroom teacher's discretion. The instructional activities may have introduced biomimicry as a concept, but they might not have allowed for deep exploration, hands-on experimentation, or reflection—elements that are often critical for fostering engagement and shifts in perception. Furthermore, the instrument used to measure students' perceptions of STEM and STEM careers was originally developed in English and translated into Finnish. Despite efforts to ensure linguistic and conceptual equivalence, nuances in meaning may have been lost or altered in translation, potentially affecting the accuracy with which student perceptions were captured. Similarly, the language of instruction throughout the treatment phase was Finnish. Owing to lack of sufficient fluency in Finnish language on part of the author, a wholistic understanding of teacher-student interactions and student behaviours was limited. In addition, the study employed a quasi-experimental design in which students were assigned to treatment and CGs based on existing classroom divisions rather than random assignment. This non-random allocation, necessitated by practical constraints, may have introduced selection bias or pre-existing group differences that could confound the interpretation of results. The relatively small sample size also limits the generalizability of the findings. The power to detect small but meaningful effects may have been insufficient, especially given natural variability in student perceptions and engagement. The study was conducted in a single school context, and results may not reflect the broader population of 5th grade students. Finally, student self-report measures can be influenced by social desirability, misunderstanding of items, or temporary mood states, which might not accurately reflect their true perceptions. The novelty of the topic, classroom environment, and teacher delivery may also have influenced how students responded to the survey.

These limitations suggest the need for caution in drawing broad conclusions. Further research with larger samples, longer intervention periods, and more robust instructional designs, ideally

incorporating random assignment where feasible could provide a much more holistic picture of the effects of biomimicry on student perceptions of STEM.

References

Baker, C. K., & Galanti, T. M. (2017). Integrating STEM in elementary classrooms using model-eliciting activities: responsive professional development for mathematics coaches and teachers [Article]. *International Journal of STEM Education*, *4*(1), 10–10. https://doi.org/10.1186/s40594-017-0066-3

Benyus, J. M. (2002). *Biomimicry : Innovation inspired by nature*. Perennial.

Bilici, S., Küpeli, M. A., & Guzey, S. S. (2021). Inspired by nature: an engineering design-based biomimicry activity. *Science Activities*, *58*(2), 77–88. https://doi.org/10.1080/00368121.2021.1918049

Buck, N. T. (2017). The art of imitating life: The potential contribution of biomimicry in shaping the future of our cities. *Environment and Planning B: Urban Analytics and City Science*, *44*(1), 120–140. https://doi.org/10.1177/0265813515611417

Burrows, A., Wickizer, G., Meyer, H., & Borowczak, M. (2013). *Enhancing pedagogy with context and partnerships: Science in hand*. *54*. www.eng.uc.edu/STEP.

Ching, Y.-H., Yang, D., Wang, S., Baek, Y., Swanson, S., & Chittoori, B. (2019). Elementary school student development of STEM attitudes and perceived learning in a STEM integrated robotics curriculum [Article]. *TechTrends*, *63*(5), 590–601. https://doi.org/10.1007/s11528-019-00388-0

Deák, C., Kumar, B., Szabó, I., Nagy, G., & Szentesi, S. (2021). Evolution of new approaches in pedagogy and STEM with inquiry-based learning and post-pandemic scenarios. In *Education Sciences* (Vol. 11, Issue 7). MDPI AG. https://doi.org/10.3390/educsci11070319

DeVellis, R. F. (1991). *Scale development : Theory and applications* [Book]. SAGE.

Dong, Y., Wang, J., Yang, Y., & Kurup, P. M. (2020). Understanding intrinsic challenges to STEM instructional practices for Chinese teachers based on their beliefs and knowledge base [Article]. *International Journal of STEM Education*, *7*(1), 1–12. https://doi.org/10.1186/s40594-020-00245-0

English, L. D. (2016). STEM education K-12: perspectives on integration. In *International Journal of STEM Education* (Vol. 3, Issue 1). Springer. https://doi.org/10.1186/s40594-016-0036-1

Faragalla, A. M. A., & Asadi, S. (2022). Biomimetic design for adaptive building caçades: A paradigm shift towards environmentally conscious architecture. *Energies 2022, Vol. 15, Page 5390*, *15*(15), 5390. https://doi.org/10.3390/EN15155390

Finnish National Agency for Education (FNAE). (2016). National core curriculum for basic education 2014. *Finnish National Agency for Education*.

Finnish National Board On Research Integrity (Tutkimuseettinen Neuvottelukunta Forskningsetiska Delegationen (TENK)) *The ethical principles of research with human participants and ethical review in the human sciences in Finland Finnish National Board on Research Integrity TENK guidelines 2019*. (n.d.).

Fitzgerald, M., Danaia, L., & McKinnon, D. H. (2019). Barriers inhibiting inquiry-based science teaching and potential solutions: Perceptions of positively inclined early adopters. *Research in Science Education*, *49*(2), 543–566. https://doi.org/10.1007/S11165-017-9623-5/FIGURES/7

Fraenkel, J. R., & Wallen, N. E. (2019). *How to design and evaluate research in education* (N. E. Wallen & H. H. Hyun, Eds.; Tenth edition.) [Book]. McGraw Hill Education.

Fredricks, J. A., Blumenfeld, P. C., & Paris, A. H. (2004). School engagement: Potential of the concept, state of the evidence. *Review of Educational Research*, *74*(1), 59–109. https://doi.org/10.3102/00346543074001059

Fried, E., Martin, A., Esler, A., Tran, A., & Corwin, L. (2020). Design-based learning for a sustainable future: student outcomes resulting from a biomimicry curriculum in an evolution course. *Evolution: Education and Outreach*, *13*(1), 1–22. https://doi.org/10.1186/S12052-020-00136-6/TABLES/6

Gremmen, B. (2022). Regenerative agriculture as a biomimetic technology. *Outlook on Agriculture*, *51*(1), 39–45. https://doi.org/10.1177/00307270211070317

Gyasi, J. F., Zheng, L., & Zhou, Y. (2021). Perusing the past to propel the future: A systematic review of stem learning activity based on activity theory [Article]. *Sustainability*, *13*(16), 8828. https://doi.org/10.3390/su13168828

Handley, I. M., Brown, E. R., Moss-Racusin, C. A., & Smith, J. L. (2015). Quality of evidence revealing subtle gender biases in science is in the eye of the beholder. *Proceedings of the National Academy of Sciences*, *112*(43), 13201–13206. https://doi.org/10.1073/pnas.1510649112

Hanif, S., Wijaya, A. F. C., & Winarno, N. (2019). Enhancing students' creativity through STEM project-based learning. *Journal of Science Learning*, *2*(2), 50. https://doi.org/10.17509/jsl.v2i2.13271

Hassan, F. H. F., Ali, K. A. Y., & Ahmed, S. A. M. (2023). Biomimicry as an approach to improve daylighting performance in office buildings in Assiut city, Egypt [Article]. *Journal of Daylighting*, *10*(1), 1–16. https://doi.org/10.15627/jd.2023.1

Ilieva, L., Ursano, I., Traista, L., Hoffmann, B., & Dahy, H. (2022). Biomimicry as a Sustainable Design Methodology— Introducing the 'Biomimicry for Sustainability' Framework [Article]. *Biomimetics (Basel, Switzerland)*, *7*(2), 37. https://doi.org/10.3390/biomimetics7020037

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

Kelley, T. R., Knowles, J. G., Holland, J. D., & Han, J. (2020). Increasing high school teachers self-efficacy for integrated STEM instruction through a collaborative community of practice. *International Journal of STEM Education*, *7*(1). https://doi.org/10.1186/s40594-020-00211-w

Kennedy, B. S. (2017). The de Mestral project: Using macro photo-journaling to stimulate interest in bio-inspired design and science, technology, engineering and mathematics disciplines [Article].

International Journal of Design & Nature and Ecodynamics, *12*(2), 185–193. https://doi.org/10.2495/DNE-V12-N2-185-193

Kennedy, T., & Odell, M. (2014). Engaging students in STEM education. *Science Education International*.

Krapp, A., & Prenzel, M. (2011). Research on interest in science: Theories, methods, and findings [Article]. *International Journal of Science Education*, *33*(1), 27–50. https://doi.org/10.1080/09500693.2010.518645

Kwon, H., Capraro, R. M., & Capraro, M. M. (2021). When I believe, I can: Success STEMs from my perceptions. *Canadian Journal of Science, Mathematics and Technology Education*, *21*(1), 67–85. https://doi.org/10.1007/S42330-020-00132-4/METRICS

Lashari, T. A., Alias, M., Kesot, M. J., & Akasah, Z. A. (2013). An affective-cognitive teaching and learning approach for enhanced behavioural engagements among engineering students. *Engineering Education*, *8*(2), 65–76. https://doi.org/10.11120/ENED.2013.00011

Lian, Y., Tsang, K. K., & Zhang, Y. (2021). The construction and sustainability of teachers' positive emotions toward stem educational work. *Sustainability (Switzerland)*, *13*(11). https://doi.org/10.3390/su13115769

Linder, B., & Huang, J. (2022). Beyond structure-function: Getting at sustainability within biomimicry pedagogy. *Biomimetics 2022, Vol. 7, Page 90*, *7*(3), 90. https://doi.org/10.3390/BIOMIMETICS7030090

Machado-Casas, M., Talati, K., & Baron, A. (2020). STEM access for Latina bilingual teacher candidates: Discrimination en la educación How do informal programs motivate women to pursue STEM related [Article]. *Tequio (En Línea)*, *3*(9), 9–22. https://doi.org/10.53331/teq.v3i9.6409

Martins, J., Cunha, J., Lopes, S., Moreira, T., & Rosário, P. (2022). School engagement in elementary school: A systematic review of 35 years of research. *Educational Psychology Review*, *34*(2), 793–849. https://doi.org/10.1007/S10648-021-09642-5/METRICS

Mayes, R., & Rittschof, K. (2021). Development of interdisciplinary STEM impact measures of student attitudes and reasoning. *Frontiers in Education*, *6*, 631684. https://doi.org/10.3389/FEDUC.2021.631684/BIBTEX

Minner, D. D., Levy, A. J., & Century, J. (2010). Inquiry-based science instruction-what is it and does it matter? Results from a research synthesis years 1984 to 2002 [Article]. *Journal of Research in Science Teaching*, *47*(4), 474–496. https://doi.org/10.1002/tea.20347

Mohr-Schroeder, M. J., Jackson, C., Miller, M., Walcott, B., Little, D. L., Speler, L., Schooler, W., & Schroeder, D. C. (2014). Developing middle school students' interests in STEM via summer learning experiences [Article]. *School Science and Mathematics*, *114*(6), 291–301. https://doi.org/10.1111/ssm.12079

Moore, T. J., Stohlmann, M. S., Wang, H.-H., Tank, K. M., Glancy, A. W., & Roehrig, G. H. (2014). *Implementation and integration of engineering in K–12 STEM Education*. http://ebookcentral.proquest.com/lib/kutu/detail.action?docID=3121265.

Moote, J. K., Williams, J. M., & Sproule, J. (2013). When students take control: Investigating the impact of the CREST inquiry-based learning program on self-regulated processes and related motivations in young science students [Article]. *Journal of Cognitive Education and Psychology*, *12*(2), 178–196. https://doi.org/10.1891/1945-8959.12.2.178

Morgan, M., Butler, M., Thota, N., & Sinclair, J. (2018). How CS academics view student engagement [Proceeding]. *Proceedings of the 23rd Annual ACM Conference on Innovation and Technology in Computer Science Education*, 284–289. https://doi.org/10.1145/3197091.3197092

Moshayedi, A. J., Roy, A. S., Kolahdooz, A., & Shuxin, Y. (2022). *Deep learning application pros and cons over algorithm*. https://doi.org/10.4108/10.4108/airo.v1i.19

Movahedzadeh, F., Patwell, R., Rieker, J. E., & Gonzalez, T. (2012). Project-based learning to promote effective learning in biotechnology courses. *Education Research International*, *2012*, 1–8. https://doi.org/10.1155/2012/536024

Murphy, S., MacDonald, A., Danaia, L., & Wang, C. (2019). An analysis of Australian STEM education strategies [Article]. *Policy Futures in Education*, *17*(2), 122–139. https://doi.org/10.1177/1478210318774190

Oliveras-Ortiz, Y., Bouillion, D. E., & Asbury, L. (2021). Learning spaces matter: Student engagement in new learning environments [Article]. *Journal of Education (Boston, Mass.)*, *201*(3), 174–182. https://doi.org/10.1177/0022057420908062

Oppong-Nuako, J., Shore, B. M., Saunders-Stewart, K. S., & Gyles, P. D. T. (2015). Using brief teacher interviews to assess the extent of inquiry in classrooms [Article]. *Journal of Advanced Academics*, *26*(3), 197–226. https://doi.org/10.1177/1932202X15588368

Othmani, N. I., Mohamed, S. A., Abdul Hamid, N. H., Ramlee, N., Yeo, L. B., & Mohd Yunos, M. Y. (2022). Reviewing biomimicry design case studies as a solution to sustainable design [Article]. *Environmental Science and Pollution Research International*, *29*(46), 69327–69340. https://doi.org/10.1007/s11356-022-22342-z

Ouallane, A. A., Bahnasse, A., Bakali, A., & Talea, M. (2022). Overview of road traffic management solutions based on IoT and AI. *Procedia Computer Science*, *198*, 518–523. https://doi.org/https://doi.org/10.1016/j.procs.2021.12.279

Palsa, L., & Mertala, P. (2019). Multiliteracies in local curricula: conceptual contextualizations of transversal competence in the finnish curricular framework. *Nordic Journal of Studies in Educational Policy*, *5*(2), 114–126. https://doi.org/10.1080/20020317.2019.1635845;SUBPAGE:STRING:FULL

Pearce, M. (2016). *Biomimicry architecture*.

Perdana, R., Apriani, A.-N., Richardo, R., Rochaendi, E., & Kusuma, C. (2021). Elementary students' attitudes towards STEM and 21st-century skills [Article]. *International Journal of Evaluation and Research in Education*, *10*(3), 1080. https://doi.org/10.11591/IJERE.V10I3.21389

Peters-Burton, E. E., House, A., Peters, V., & Remold, J. (2019). Understanding STEM-focused elementary schools: Case study of Walter Bracken STEAM Academy. *School Science and Mathematics*, *119*(8), 446–456. https://doi.org/10.1111/SSM.12372

Riegle-Crumb, C., Morton, K., Moore, C., Chimonidou, A., Labrake, C., & Kopp, S. (2015). Do inquiring minds have positive attitudes? The science education of preservice elementary teachers [Article]. *Science Education (Salem, Mass.)*, *99*(5), 819–836. https://doi.org/10.1002/sce.21177

Roberts, T., Jackson, C., Mohr-Schroeder, M. J., Bush, S. B., Maiorca, C., Cavalcanti, M., Craig Schroeder, D., Delaney, A., Putnam, L., & Cremeans, C. (2018). Students' perceptions of STEM learning after participating in a summer informal learning experience. *International Journal of STEM Education*, *5*(1), 1–14. https://doi.org/10.1186/S40594-018-0133-4/FIGURES/1

Roehrig, G. H., Dare, E. A., Ellis, J. A., & Ring-Whalen, E. (2021). Beyond the basics: A detailed conceptual framework of integrated STEM. *Disciplinary and Interdisciplinary Science Education Research*, *3*(1). https://doi.org/10.1186/s43031-021-00041-y

Roehrig, G. H., Moore, T. J., Wang, H. H., & Park, M. S. (2012). Is adding the E enough? Investigating the impact of K-12 engineering standards on the implementation of STEM Integration. *School Science and Mathematics*, *112*(1), 31–44. https://doi.org/10.1111/j.1949-8594.2011.00112.x

Sahin, A., Ayar, M. C., & Adiguzel, T. (2014). STEM related after-school program activities and associated outcomes on student learning [Article]. *Educational Sciences : Theory & Practice*, *14*(1), 309. https://doi.org/10.12738/estp.2014.1.1876

SAVRAN GENCER, A., DOĞAN, H., & BİLEN, K. (2020). Developing biomimicry STEM activity by querying the relationship between structure and function in organisms. *Turkish Journal of Education*, *9*(1), 64–105. https://doi.org/10.19128/turje.643785

Shaik, T., Tao, X., Higgins, N., Li, L., Gururajan, R., Zhou, X., & Acharya, U. R. (2023). Remote patient monitoring using artificial intelligence: Current state, applications, and challenges. *WIREs Data Mining and Knowledge Discovery*, *13*(2), e1485. https://doi.org/https://doi.org/10.1002/widm.1485

Shin, J. E. L., Levy, S. R., & London, B. (2016). Effects of role model exposure on STEM and non-STEM student engagement [Article]. *Journal of Applied Social Psychology*, *46*(7), 410–427. https://doi.org/10.1111/jasp.12371

Siverling, E. A., Suazo-Flores, E., Mathis, C. A., & Moore, T. J. (2019). Students' use of STEM content in design justifications during engineering design-based STEM integration. *School Science and Mathematics*, *119*(8), 457–474. https://doi.org/10.1111/SSM.12373

Smith, J., & Karr-Kidwell, P. (2000). *The interdisciplinary curriculum: A literary review and a manual for administrators and teachers* [Unknown].

Struyf, A., De Loof, H., Boeve-de Pauw, J., & Van Petegem, P. (2019). Students' engagement in different STEM learning environments: integrated STEM education as promising practice? *International Journal of Science Education*, *41*(10), 1387–1407. https://doi.org/10.1080/09500693.2019.1607983

Tank, K. M., Moore, T. J., Dorie, B. L., Gajdzik, E., Terri Sanger, M., Rynearson, A. M., & Mann, E. F. (2018). *Engineering in early elementary classrooms through the integration of high-quality literature, design, and STEM+C content*. 175–201. https://doi.org/10.1007/978-981-10-8621-2_9

Tanyanyiwa, V. I., & Juba, O. S. (2018). Green buildings and water management in Harare, Zimbabwe Article history Abstract Keywords Eco-friendly Green building Recycling Sustainability Water efficiency Waste water. In *UPLanD-Journal of Urban Planning* (Vol. 3, Issue 2). http://upland.it

The Statesman. (2024, January 26). *British-Indian faces trial in Spain after 'Taliban' joke to blow up plane*. The Statesman.

Thibaut, L., Ceuppens, S., De Loof, H., De Meester, J., Goovaerts, L., Struyf, A., Boeve-de Pauw, J., Dehaene, W., Deprez, J., De Cock, M., Hellinckx, L., Knipprath, H., Langie, G., Struyven, K., Van de Velde, D., Van Petegem, P., & Depaepe, F. (2018). Integrated STEM education: A systematic review of instructional practices in secondary education. *European Journal of STEM Education*, *3*(1). https://doi.org/10.20897/ejsteme/85525

Toma, R. B., & Greca, I. M. (2018). The effect of integrative STEM instruction on elementary students' attitudes toward science [Article]. *Eurasia Journal of Mathematics, Science and Technology Education*, *14*(4), 1383–1395. https://doi.org/10.29333/ejmste/83676

Tuong, H. A., Nam, P. S., Hau, N. H., Tien, V. T. B., Lavicza, Z., & Hougton, T. (2023). Utilising STEM-based practices to enhance mathematics teaching in Vietnam: Developing students' real-world problem-solving and 21st century skills. *Journal of Technology and Science Education*, *13*(1), 73–91. https://doi.org/10.3926/jotse.1790

Tyler-Wood, T., Knezek, G., & Christensen, R. (2010). Instruments for assessing interest in STEM content and careers. In *Jl. of Technology and Teacher Education* (Vol. 18, Issue 2).

Vasinayanuwatana, T., & Plianram, S. (2023). Biomimicry in STEM education. *Research in Integrated STEM Education*, *1*(2), 316–340. https://doi.org/10.1163/27726673-bja00011

Verma, A., & Ali, M. F. (2023). Impacting career choices of historically underserved secondary students by designing near-peer directed acid–base thematic laboratory activities to enhance STEM interest [Article]. *Journal of Chemical Education*, *100*(9), 3434–3444. https://doi.org/10.1021/acs.jchemed.3c00434

Vincent, J. F. V., Bogatyreva, O. A., Bogatyrev, N. R., Bowyer, A., & Pahl, A. K. (2006). Biomimetics: Its practice and theory. *Journal of the Royal Society Interface*, *3*(9), 471–482. https://doi.org/10.1098/RSIF.2006.0127

Vitikka, E., Krokfors, L., & Rikabi, L. (2016). The Finnish National Core Curriculum. *Miracle of Education*, 83–90. https://doi.org/10.1007/978-94-6300-776-4_6

Volstad, N. L., & Boks, C. (2012). On the use of biomimicry as a useful tool for the industrial Designer [Article]. *Sustainable Development (Bradford, West Yorkshire, England)*, *20*(3), 189–199. https://doi.org/10.1002/sd.1535

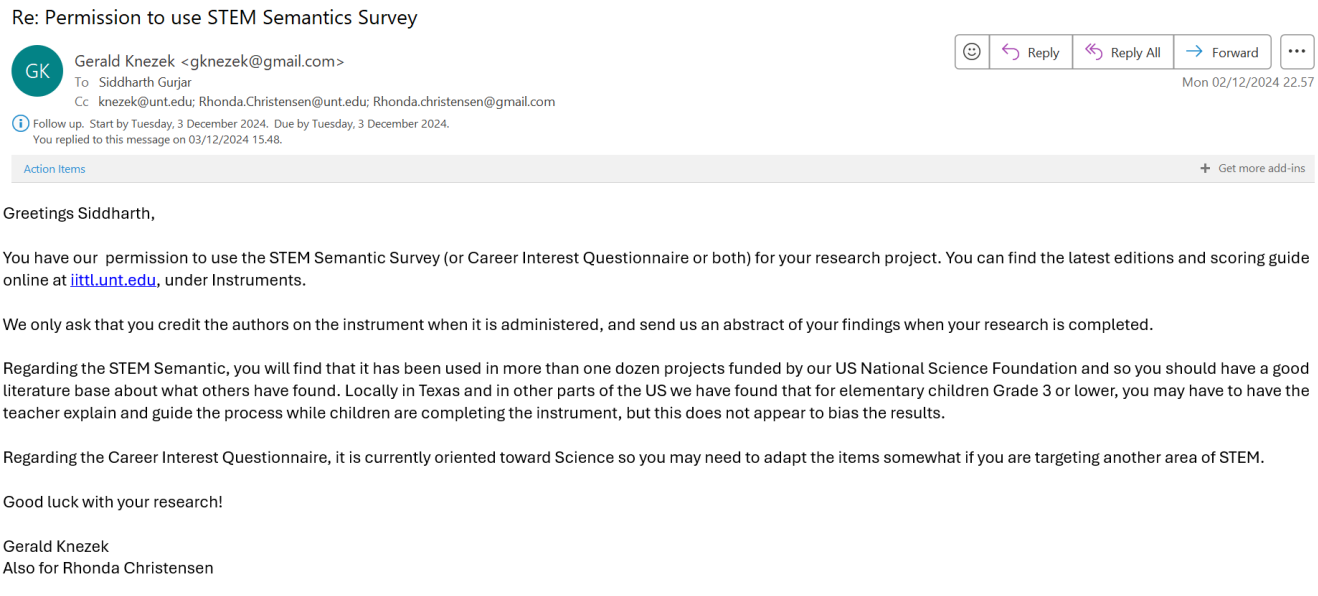
Wang, M. Te, Degol, J., & Ye, F. (2015). Math achievement is important, but task values are critical, too: Examining the intellectual and motivational factors leading to gender disparities in STEM careers. *Frontiers in Psychology*, *6*(FEB), 125951. https://doi.org/10.3389/FPSYG.2015.00036/BIBTEX

Yanez, G. A., Thumlert, K., de Castell, S., & Jenson, J. (2019). Pathways to sustainable futures: A "production pedagogy" model for STEM education. *Futures*, *108*, 27–36. https://doi.org/10.1016/j.futures.2019.02.021

Yoon, S. Y., Dyehouse, M., Lucietto, A. M., Diefes-Dux, H. A., & Capobianco, B. M. (2014). The effects of integrated science, technology, and engineering education on elementary students' knowledge and identity Development [Article]. *School Science and Mathematics*, *114*(8), 380–391. https://doi.org/10.1111/ssm.12090

Appendices

Appendix 1 Permission to use STEM Semantics Survey



Re: Permission to use STEM Semantics Survey

GK Gerald Knezek <gknezek@gmail.com>
To Siddharth Gurjar
Cc knezek@unt.edu; Rhonda.Christensen@unt.edu; Rhonda.christensen@gmail.com

Reply | Reply All | Forward
Mon 02/12/2024 22.57

Follow up. Start by Tuesday, 3 December 2024. Due by Tuesday, 3 December 2024.
You replied to this message on 03/12/2024 15.48.

Action Items | Get more add-ins

Greetings Siddharth,

You have our permission to use the STEM Semantic Survey (or Career Interest Questionnaire or both) for your research project. You can find the latest editions and scoring guide online at iittl.unt.edu, under Instruments.

We only ask that you credit the authors on the instrument when it is administered, and send us an abstract of your findings when your research is completed.

Regarding the STEM Semantic, you will find that it has been used in more than one dozen projects funded by our US National Science Foundation and so you should have a good literature base about what others have found. Locally in Texas and in other parts of the US we have found that for elementary children Grade 3 or lower, you may have to have the teacher explain and guide the process while children are completing the instrument, but this does not appear to bias the results.

Regarding the Career Interest Questionnaire, it is currently oriented toward Science so you may need to adapt the items somewhat if you are targeting another area of STEM.

Good luck with your research!

Gerald Knezek
Also for Rhonda Christensen

Appendix 2a STEM Semantics Survey (Original)

STEM Semantics Survey

Gender: M / F

This five-part questionnaire is designed to assess your perceptions of scientific disciplines. It should require about 5 minutes of your time. Usually it is best to respond with your first impression, without giving a question much thought. Your answers will remain confidential.

ID: _____ **School:_____**	Use the assigned ID or the year and day of your birthday (ex: 9925 if born on the 25th day of any month in 1999.

Instructions: Choose one circle between each adjective pair to indicate how you feel about the object.

To me, SCIENCE is:

1.	fascinating	①	②	③	④	⑤	⑥	⑦	ordinary
2.	appealing	①	②	③	④	⑤	⑥	⑦	unappealing
3.	exciting	①	②	③	④	⑤	⑥	⑦	unexciting
4.	means nothing	①	②	③	④	⑤	⑥	⑦	means a lot
5.	boring	①	②	③	④	⑤	⑥	⑦	interesting

To me, MATH is:

1.	boring	①	②	③	④	⑤	⑥	⑦	interesting
2.	appealing	①	②	③	④	⑤	⑥	⑦	unappealing
3.	fascinating	①	②	③	④	⑤	⑥	⑦	ordinary
4.	exciting	①	②	③	④	⑤	⑥	⑦	unexciting
5.	means nothing	①	②	③	④	⑤	⑥	⑦	means a lot

To me, ENGINEERING is:

1.	appealing	①	②	③	④	⑤	⑥	⑦	unappealing
2.	fascinating	①	②	③	④	⑤	⑥	⑦	ordinary
3.	means nothing	①	②	③	④	⑤	⑥	⑦	means a lot
4.	exciting	①	②	③	④	⑤	⑥	⑦	unexciting
5.	boring	①	②	③	④	⑤	⑥	⑦	interesting

To me, TECHNOLOGY is:

1.	appealing	①	②	③	④	⑤	⑥	⑦	unappealing
2.	means nothing	①	②	③	④	⑤	⑥	⑦	means a lot
3.	boring	①	②	③	④	⑤	⑥	⑦	interesting
4.	exciting	①	②	③	④	⑤	⑥	⑦	unexciting
5.	fascinating	①	②	③	④	⑤	⑥	⑦	ordinary

To me, a CAREER in science, technology, engineering, or mathematics (is):

1.	means nothing	①	②	③	④	⑤	⑥	⑦	means a lot
2.	boring	①	②	③	④	⑤	⑥	⑦	interesting
3.	exciting	①	②	③	④	⑤	⑥	⑦	unexciting
4.	fascinating	①	②	③	④	⑤	⑥	⑦	ordinary
5.	appealing	①	②	③	④	⑤	⑥	⑦	unappealing

Appendix 2b STEM Semantics Survey (Finnish)

Isän ammatti:

Äidin ammatti:

Tämä kyselylomake on suunniteltu arvioimaan käsitystäsi eri tieteistä. Älä mieti vastausta liikaa, vaan kerro mikä on ensivaikutelmasi asiasta. Vastauksesi pysyvät luottamuksellisina.

Ohjeet: Valitse yksi ympyrä kunkin adjektiiviparin väliltä osoittaaksesi, mitä sinä ajattelet asiasta.

Minusta TIEDE on:						
1. kiehtovaa	1	2	3	4	5	tavallista
2. vetoavaa	1	2	3	4	5	ei houkuttelevaa
3. jännittävää	1	2	3	4	5	jännityksetöntä
4. merkityksetöntä	1	2	3	4	5	tärkeää
5. tylsää	1	2	3	4	5	mielenkiintoista
Minusta MATEMATIIKKA on:						
1. kiehtovaa	1	2	3	4	5	tavallista
2. vetoavaa	1	2	3	4	5	ei houkuttelevaa
3. jännittävää	1	2	3	4	5	jännityksetöntä
4. merkityksetöntä	1	2	3	4	5	tärkeää
5. tylsää	1	2	3	4	5	mielenkiintoista
Minusta INSINÖÖRITAITO on:						
1. kiehtovaa	1	2	3	4	5	tavallista
2. vetoavaa	1	2	3	4	5	ei houkuttelevaa
3. jännittävää	1	2	3	4	5	jännityksetöntä
4. merkityksetöntä	1	2	3	4	5	tärkeää
5. tylsää	1	2	3	4	5	mielenkiintoista
Minusta TEKNOLOGIA on:						
1. kiehtovaa	1	2	3	4	5	tavallista
2. vetoavaa	1	2	3	4	5	ei houkuttelevaa
3. jännittävää	1	2	3	4	5	jännityksetöntä
4. merkityksetöntä	1	2	3	4	5	tärkeää
5. tylsää	1	2	3	4	5	mielenkiintoista
Minusta ura/ammatti tieteen, tekniikan, tekniikan tai matematiikan alalla (on):						
1. kiehtovaa	1	2	3	4	5	tavallista
2. vetoavaa	1	2	3	4	5	ei houkuttelevaa
3. jännittävää	1	2	3	4	5	jännityksetöntä
4. merkityksetöntä	1	2	3	4	5	tärkeää
5. tylsää	1	2	3	4	5	mielenkiintoista

Appendix 3 Consent Form for teacher interview

Consent Form For The Participants

Hello, I am Siddharth Gurjar and I am a Master's Degree student at the University of Turku. I am conducting a study to investigate the effect of integrating Biomimicry in STEM subject lessons on students' engagement and interest in STEM subjects and careers. As a part of the study, I want to conduct interviews with you in order to learn about your perception of your students' engagement in STEM related content and your observations. Your participation should be voluntarily.

The interview will be in a one-to-one setting. It is not a requirement of the program that you teach/study. Participating in the interview has no risks or benefits in terms of your reappointment. If you volunteer for the interview, the raw data that you provide will not be provided to the school you are teaching or to other institutions. The interview does not involve any psychological and physical tasks and consequently risks, that require participants to respond. The interview is not likely to provide the participants with any benefits, apart from being involved in an educational research addressing their ideas about risks involved by using information provided. I will ask if I can audio-record the interview. You may allow, refuse, or allow for only certain parts of the interview. I may contact you for further explanation on certain topics after this interview by phone, via e-mail/internet, or in person and you may either refuse to provide further information or answer my further questions in these contacts. I will ask you whether I may include those contacts as data and will act according to your wish.

If you volunteer to participate in the interview, your privacy will be protected to the maximum extent possible. I will keep your name in our records, but will not provide any member of the school you are teaching and students at the school. I will be the sole researcher(s) who has the access to the data you provide. The data you provide will be in a safe place where other people have no access. This form is prepared as two copies, one for your

records, and one for the study. Your name and signature will appear on these two copies of form since I ask you for your participation. One copy will be the copy of the researcher for further reference and the other copy will be your copy. The data that you provide will be archived for 2 years and then it will be destroyed.

You are free to ask questions at any moment of the interview. If you have questions before deciding on volunteering please feel free to ask. You may refuse to participate before the interview begins, discontinue at any time, or skip any questions that may make you feel uncomfortable. If you want to ask me any further questions in the future about the study please feel free to contact me at the following address (You may contact me anonymously, if you prefer): +358 45 146 43 25 (phone), siddharth.s.gurjar@utu.fi (e-mail).

If you want to volunteer for the interview please write your name and surname, the date and provide your signature on space provided below.

Thank you.

Name, Surname: Signature :

Date :

Appendix 4 Consent Form

Suostumuslomake tutkimukseen osallistumisesta

Tutkimuksen otsikko: Biomimetiikan integrointi STEM-opetukseen: Vaikutus oppilaiden käsityksiin STEM-oppimisesta ja -urista

Hyvä huoltaja,

Minä, **Siddharth Gurjar**, suoritan tutkimusta osana maisterintutkielmaani **Turun yliopistossa**. Tutkimus käsittelee biomimetiikan integroimisen vaikutusta STEM (Science, Technology, Engineering ja Mathematics) -aiheiden opetukseen, oppilaiden kiinnostukseen ja heidän näkemyksiinsä STEM-aloista ja uramahdollisuuksista. Lyhyesti sanottuna biomimetiikka tarkoittaa luonnon ratkaisujen tarkastelua luonnon ongelmiin ja näiden ratkaisujen hyödyntämistä ihmisten ongelmien ratkaisemisessa.

Tutkimuksen tarkoitus
Tämän tutkimuksen tavoitteena on tutkia, voiko biomimetiikkaa opetustapana hyödyntämällä lisätä oppilaiden kiinnostusta STEM-aiheisiin ja vaikuttaa heidän uratavoitteisiinsa STEM-aloilla.

Mitä osallistuminen sisältää
Lapsenne osallistuminen sisältää seuraavat:

- Neljän lyhyen kyselyn täyttäminen koulupäivän aikana. Kyselyissä arvioidaan kiinnostusta ja sitoutumista STEM-aiheisiin ja -uriin asteikolla 1–5.
- STEM-tuntien kokeminen, joissa biomimetiikan käsitteet ovat mukana. Näiden tuntien aikana oppilaat tutustuvat biomimetiikan periaatteisiin ja käyttävät niitä ratkaisujen kehittämiseen valittuihin ongelmiin. Tunnit sisältävät ainoastaan ideointia ja mahdollisesti prototyyppien rakentamista helposti saatavilla olevilla materiaaleilla.

Lisäksi opettajia haastatellaan heidän näkemyksistään oppilaiden sitoutumisesta STEM-aiheisiin ennen ja jälkeen biomimetiikkaa sisältävien tuntien.

Aikataulu
Tutkimus toteutetaan **yhdeksän viikon aikana, 6.1.2025–28.2.2025.**

- **Viikot 2 ja 3:** Opettajahaastattelut, ensimmäinen oppilaskysely
- **Viikko 4:** Toinen oppilaskysely
- **Viikot 5 ja 6:** Biomimetiikan integrointia sisältävät tunnit
- **Viikko 7:** Lopulliset opettajahaastattelut ja kolmas oppilaskysely
- **Viikko 9:** Viimeinen oppilaskysely

Vapaaehtoisuus
Tutkimukseen osallistuminen on täysin vapaaehtoista. Lapsenne voi lopettaa osallistumisen milloin tahansa ilman vaikutusta koulunkäyntiin.

Luottamuksellisuus
Kaikki kerätyt tiedot käsitellään luottamuksellisesti. Henkilökohtaisia tunnistetietoja ei julkaista tutkimuksen tuloksissa.

Tutkimusaineisto ja tulosten julkaiseminen
Tutkimusaineisto kerätään Suomen kansallisen tutkimuseettisen neuvottelukunnan (TENK) ohjeiden mukaisesti, ja aineisto kerätään anonyymisti. Tiedot analysoidaan tutkijan toimesta ja hävitetään tutkielman valmistumisen jälkeen.

Tutkimuksen tulokset julkaistaan sähköisesti osana Turun Yliopiston arkistoja ja niitä voidaan käyttää vain akateemisissa esityksissä. Tulokset voidaan myös julkaista akateemisissa lehdissä. Kuitenkin kaikki osallistujat, mukaan lukien koulu, opettajat ja oppilaat, pysyvät nimettöminä.

Tutkijan yhteystiedot
Jos teillä on kysymyksiä tai huolenaiheita, ottakaa yhteyttä:
Siddharth Gurjar
Sähköposti: siddharth.s.gurjar@utu.fi

Suostumus
Allekirjoittamalla tämän lomakkeen vahvistatte ymmärtävänne tutkimuksen yksityiskohdat ja annatte suostumuksenne lapsenne osallistumiselle.

Huoltajan suostumuslomake

Lapsen nimi: _____

Huoltajan nimi: _____

Huoltajan allekirjoitus: _____

Päivämäärä: _____

Consent Form for Participation in Research Study

Study Title: *Integrating Biomimicry in STEM Lessons: Influence on Student Perception toward STEM Learning and Careers*

Dear Parent/Guardian,

I, **Siddharth Gurjar**, am conducting a research study as part of my master's thesis at the **University of Turku**. The study investigates how integrating biomimicry in STEM (Science, Technology, Engineering, and Mathematics) lessons affects students' engagement and perceptions of STEM subjects and careers. Biomimicry, in brief, is looking at nature's solutions to problems in the natural world and emulating those solutions to solve human world problems.

Purpose of the Study
This study aims to explore whether biomimicry as a teaching approach can enhance students' interest and engagement in STEM education and influence their career aspirations in STEM-related fields.

What Participation Involves
Your child's participation will include:

- Completing four short surveys about their interest and engagement in STEM subjects and careers during the school day. The students will rate the four STEM subjects on a scale of 1 to 5.
- Experiencing STEM lessons integrated with biomimicry concepts delivered by their teachers. As part of these lessons, students will become familiar with the discipline of biomimicry and use it themselves to create solutions for chosen problems. The lessons will involve only idea generation and possibly prototyping with materials easily available.

Additionally, teachers will be interviewed to gather their perspectives on their perceptions about students' engagement in STEM pre- and post-biomimicry integrated lessons.

Schedule of Activities
The study will take place over a nine-week period starting from 06.01.2025 until 28.02.2025.

- **Weeks 2 & 3:** Teacher interviews, first student survey
- **Week 4:** Second student survey
- **Weeks 5 & 6:** Lessons with biomimicry integration.
- **Week 7:** Final teacher interviews and third student survey.
- **Week 9:** Last student survey.

Voluntary Participation
Participation in this study is completely voluntary. Your child can withdraw at any time without any impact on their school experience.

Confidentiality
All information collected will be handled confidentially. No personal identifying information will appear in the study's results or publications.

Research Data and Publication of Results
Research Data are collected in accordance with the guidelines of the Finnish National Board on Research Integrity, and research data are collected anonymously. The data will be collected and analysed by the researcher and will be destroyed upon the completion of the thesis.

The findings of this study will be published electronically as part of the University of Turku archives and may be used only in academic presentations. The results may also be published in academic journals. However, all participants, including the school, the teachers, and the students will remain anonymous.

Contact Information of the Researcher
If you have any questions or concerns, please contact me:
Siddharth Gurjar
Email: siddharth.s.gurjar@utu.fi

Consent
By signing below, you confirm that you understand the study details and consent for your child to participate.

Parental/Guardian Consent Form

Child's Name: _____

Parent/Guardian Name: _____

Parent/Guardian Signature: _____

Date: _____

Appendix 5

Classroom Observation Protocol

Behavioural Engagement Indicators

Behavioral Engagement Type	Indicator
Positive	Asking questions voluntarily
Positive	Responding voluntarily
Positive	Task focus and completion
Positive	Completing assignments
Positive	Being attentive (Looking at the front/teacher/SmartTV, listening attentively to the teacher)
Negative	Disruptive behaviour (e.g., talking while teacher talks, throwing objects at peers, deliberately saying something irrelevant to the lesson or task)
Negative	Distracted behaviour (Fiddling with objects, doing something irrelevant to the task at hand at a given time)
Negative	Daydreaming (not looking at the front, looking into the void)
Negative	Yawning / sleeping / slouched posture

- Observer to use event sampling, meaning observer should note occurrence of a certain behaviour according to the indicators above during each 'Lesson Stage' (T1, T2, T3, T4, T5). A 'Lesson Stage' is defined as a distinct phase in which teachers and students are engaged in activities distinct from the previous stage. Examples include 'Teacher gives instructions for the task', 'Students solve problems in pairs', or 'Students work in groups on the given project'.
- Even if a certain behaviour is exhibited by multiple students multiple times during on Lesson Stage, it is recorded only once.
- Besides recording the occurrences, observer makes notes about any out-of-the-ordinary behaviour, such as a student who is generally participative and responsive being particularly quite during a lesson or v.v.
- Frequency of each behaviour type is summed up at the end of a lesson
- At the end of the unit phase (Before Treatment and During Treatment), the total number of occurrences of positive and negative behaviours are calculated and mean is calculated.

Example: Observations during one lesson

	23.01.25 Treatment Phase: YT (Science)					
	T1	T2	T3	T4	T5	Total
Behaviour Indicators						
Asking questions voluntarily						5
Responding voluntarily	1					
Task focus and completion				1		
Completing assignments						

Being attentive		1	1		1	
Disruptive behaviour	1	1	1			7
Distracted behaviour	1		1	1		
Daydreaming			1			
Yawning / Sleeping						

Example: Total and mean at the end of a unit phase

Behaviour Indicators	Total (During treatment)	Mean (During Treatment)
Asking questions voluntarily		
Responding voluntarily		
Task focus and completion		
Completing assignments		
Being attentive	33	5.5
Disruptive behaviour		
Fiddling with objects		
Daydreaming		
Yawning / Sleeping	33	5.5

Appendix 6 Permission from school to conduct research

Tutkimuslupahakemus

Vastaaja:

-

Vastaus:

10.12.2024, 09:20 - 10.12.2024, 09:35

1. 1. Tutkimuksen päävastuullisen tekijän yhteystiedot *

Etunimi	Siddharth
Sukunimi	Gurjar
Matkapuhelin	0451464325
Sähköposti	siddharth.s.gurjar@utu.fi
Osoite	Kalliokatu 32A 22
Postinumero	26100
Postitoimipaikka	Rauma
Organisaatio.	University of Turku
Asema (esim OKL opisk.)	Master's Degree student (Turku)

2.
2. Valmistautuminen tutkimuksen tekemiseen
Lupaa haettaessa haluamme varmistua seuraavista asioista. (valmistautumattomuus lykkää luvan saamista)
Tutkimuksen päävastuullisena: *

Olen tutustunut eettiseen ohjeistukseen.
Olen tutustunut henkilötietojen käsittelyn ohjeistukseen.
Olen valinnut käyttämäni tutkimustavan ja laatinut esim. kyselylomakkeen, haastattelukysymykset tms.
Tiedän, mitä kohderyhmää haluan tutkia.
Olen laatinut tutkimukseni tiedotteen ja vaadittavat suostumukset tutkittavalle ja mahdollisen alaikäisen huoltajalle.
Olen varautunut siihen, että osa tutkittavista voi kieltäytyä tutkimuksesta tai halutessaan keskeyttää tutkimukseen osallistumisen.
Olen vastuussa aineiston säilyttämisestä ja henkilötietojen käsittelystä.

3. 3. Tutkimuksen ohjaaja (nimi, asema, sähköposti, puhelin)

Çiğdem Haser, Professor, cigdem.haser@utu.fi, +358 29 450 3896

4. 4. Muut tutkimuksen tekijät, mikäli et tee tutkimusta yksin (nimi, puhelinnumero ja sähköposti)

Ei vastauksia

5. 5. Tutkimuksen nimi *

Integrating Biomimicry in STEM Lessons: Influence on Student Perception toward STEM Learning and Careers

6. 6. Tutkimuksen taso *

pro gradu

7. Lisäselvitys mikäli tutkimus liittyy johonkin suurempaan tutkimuskokonaisuuteen

Ei vastauksia

8. 7. Tutkimuksen kuvaus lyhyesti *

Biomimicry is a design discipline which takes inspiration from nature to solve human world problems. For example, shark skin, thanks to its structure, does not allow harmful bacteria and germs to accumulate on it. The same structure can be emulated to manufacture publicly available computers or paints for walls in hospitals to keep surface free of microbes. This study aims to investigate if and how integrating basics of biomimicry can affect students' interest and engagement in STEM (Science, Technology, Engineering, and Mathematics) content and careers. Two classrooms, a control group and an experimental group, will be part of the study. Biomimicry integrated lessons (intervention) will be delivered to the experimental group and changes in student engagement will be evaluated through 2 pre-intervention , 2 post-intervention students surveys, 1 round of pre-intervention teacher interviews, and 1 post-intervention teacher interviews. Following is a tentative schedule for the study.
Sending out consent forms to parents: Week 2
First Teacher interviews: Week 2
First Student Survey: Week 2
Introduction to Biomimicry for the teachers: Week 2 or 3
Second Student Survey: Week 4
Intervention: Week 5 and 6
Second Teacher Interviews: Week 7
Third Student Survey: Week 7
Last Student Survey: Week 9
The two participant teachers have already been contacted and briefed about the study and they are willing to participate according to the current plan.

9. 8. Tutkimuksen kohderyhmä (luokkataso tai muu ryhmän määrittely) *

5th grade

10. Oppilaiden opettaja, jolta toivotaan yhteistyötä (mikäli nimi on tiedossa)

	Hilppa Jankama and Elina Heinonen

11. 9. Tiedot, joita oppilaista kerätään *

henkilötietoja kerätään, luettele mitä henkilötietoja
possibly students' guardians occupation

12. 10. Kohderyhmän oppilaiden kanssa tarvittava aika. Arvioi tunteina ja tutkitaanko yksin vai ryhmänä. *

Tuntia	10 hours

13. 11. Tutkimuksen kokonaisaikataulu *

Alkamispäivämäärä (pp/kk/vuosi)	06/01/2025
Arvioitu päättymispäivä(pp/kk/vuosi)	28/02/2025

14. 12. Tutkimuksen valmisturninen ja normaalikoulun mahdollisuus jakaa tietoa tutkimuksesta *

Sitoudun ilmoittamaan normaalikoulun johtavalle rehtorille tutkimuksen valmistumisesta ja, miten tutkimukseen voi tutustua (pääasiallisesti sähköisesti).
Sovin johtavan rehtorin kanssa tutkimuksen mahdollisesta julkaisemisesta, mikäli se olisi koulun kannalta merkityksellistä.

15. 13. Olen ilmoittanut henkilötietojen luovuttamisesta niille henkilöille, joiden tiedot olen tähän lomakkeeseen kirjannut. *

Kyllä

16. 14. Olen tutustunut tutkimusluparekisterin tietosuojaselosteeseen. Seloste on Rauman normaalikoulun nettisivuilla (https://sites.utu.fi/rnk/tutkimus-ja-kokeilu/tutkimuslupa/) *

Kyllä

17. 15. Vahvista lähetys *

Kyllä

TURUN
YLIOPISTO
UNIVERSITY
OF TURKU

Tämä dokumentti on allekirjoitettu sähköisesti Turun yliopiston UTUsign-järjestelmällä
This document has been electronically signed with UTUsign system of the University of Turku

Päiväys / Date: 10.12.2024 10:22:26 (UTC +0200)

Juha Ståhlberg
rehtori
Turun yliopisto
Organisaation varmentama (UTU-käyttäjätunnus)
Certified by organization (UTU user account)
Organisaation varmentama

Disclaimer:

In writing process of this thesis, AI tools have been used for the following purposes.

1. Assisting in information retrieval: Literature search in conjunction with traditional literature search methods.

2. Assisting in writing: Collating notes from readings into cohesive and structured text, paraphrasing and proofreading.