Empowering Young Women in STEM through Creative Making: Insights from the Hands on! STEM Makerspace Project

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Abstract

Learning becomes more effective when knowledge is applied practically and connected to learners' everyday lives. STEM subjects are still predominantly perceived as male domains [1], despite their ubiquitous relevance in daily contexts. To address this imbalance, it is essential to strengthen interest, motivation, and self-efficacy among girls and young women in STEM fields—an effort that requires innovative approaches. The maker movement is known for its creative, hands-on, and solution-oriented mindset. Here, we present our STEM Makerspace project which leverages this potential to develop new forms of engagement and motivation, particularly through STEM- and hands-on-focused maker workshops. The project is based on four core pillars: creative STEM workshops, STEM role models, the development of a STEM network, and advanced STEM projects. This contribution focuses primarily on the creative workshop formats. These workshops are currently offered on an almost weekly basis, and they are regularly attended by 10…20 participants. With them, we convert everyday interests – such as designing jewelry, accessories, or smart home tools – as entry points into low-threshold STEM practices. Participants begin by digitally modeling or coding their designs, which are then realized using tools such as 3D printers, laser cutters, or embroidery machines. Integrating blinking LEDs into textile objects, for instance, requires knowledge of materials, electronic circuits, and microcontroller programming. Within one year, already 700 young individuals have actively participated in our workshops. By connecting STEM education to the personal and creative interests of girls and young women, the project opens up sustainable pathways for a higher share of female participation and empowerment in science and technology.

Keywords: *Gender gap, makerspace, creativity, STEM education*

1. Introduction

Numerous studies indicate that girls, on average, show lower intrinsic motivation and experience less enjoyment in STEM subjects during school compared to boys [2, 3]. Importantly, this disparity does not reflect differences in ability or talent. Research consistently demonstrates that girls are equally capable in STEM domains; rather, differences in emotional engagement, interest, and perceived relevance play a decisive role in educational trajectories [4, 5].
Enjoyment and motivation are crucial predictors of academic achievement. Independent of gender, boredom and low intrinsic motivation are associated with poorer academic performance [6]. As a consequence, reduced enjoyment in STEM subjects contributes to fewer young women choosing STEM-related educational and career pathways [7-9]. This dynamic reinforces the well-documented STEM gender gap, which is reflected both in international comparisons [10] and in the persistent shortage of skilled professionals in STEM fields, particularly in countries such as Germany [11].
Against this background, a central question emerges: Can the motivation of girls and young women for STEM subjects be sustainably increased? Large-scale research syntheses suggest that motivation is not static but can be developed and reshaped across the life span [12, 13]. Moreover, research indicates that educational interventions have a stronger positive effect on groups that are stereotypically disadvantaged - such as girls in STEM - than on non-disadvantaged groups, and that such interventions are effective across all STEM disciplines [14].

One well-established approach to fostering motivation involves the use of role models, particularly women working in professions that challenge traditional gender stereotypes. Exposure to such role models supports their critical reflection, broadens perceptions of possible career pathways, and contributes to the development of positive professional self-concepts [15, 16]. In addition, a growing body of research and practice shows that creative, hands-on STEM activities can be particularly motivating for girls. Maker-based approaches that combine creativity, autonomy, and tangible outcomes have been shown to increase engagement, self-efficacy, and interest in STEM learning [17-21].

Building on these insights, in 2025 we started a project called *Hands on! STEM Makerspace* at the Friedrich Schiller University of Jena in Germany. The project was selected for a grant upon a competitive initiative of the German federal government aimed at strengthening girls' and young women's motivation and participation in STEM [22]. The project is structured around four core pillars:

(1) Delivery of creative STEM workshops that connect technical skills with everyday interests and hands-on making,

(2) Showcasing of STEM role models that provide relatable and counter-stereotypical perspectives on STEM careers,

(3) Development of a STEM network linking educational institutions, extracurricular learning spaces, and regional stakeholders, and

(4) Delivery of advanced STEM projects that enable deeper engagement and sustained participation.

This paper focuses primarily on the first pillar - the practical experiences with the creative workshop formats - and explores how maker-based learning environments can serve as effective entry points into STEM education for girls and young women.

2. STEM hands-on workshops to attract particularly girls and young women

In the Hands on! STEM Makerspace project, we design and conduct workshops that emphasize creative experimentation and the production of everyday objects. This approach has proven particularly effective in engaging girls and young women while fostering a broad range of STEM-related competencies. The workshops focus on hands-on design and digital fabrication processes, enabling participants to experience STEM skills as meaningful, accessible, and closely connected to their own interests. One of the primary goals of the project is to support the development of positive experiences of self-efficacy in STEM, even when participation represents a first point of contact with technical or scientific topics. Workshop group sizes typically range from 8 to 25 participants, depending on the event format, with an age range from approximately 5 to 30 years. However, we estimate that the majority of participants are between 12 and 17 years old.

Due to the project's strong mobile infrastructure, the workshops are not limited to the project's own makerspace, the Lichtwerkstatt at the university [23, 24], but are also conducted directly in schools, extracurricular learning environments such as youth centers, and at large public events. This flexible implementation enables the project to reach participants who would otherwise have limited or no access to STEM workshops and maker-based learning opportunities. Through this approach, more than 650 girls and young women have already participated in the project's educational activities.

To date, all workshop formats have been implemented in coeducational settings. However, future offerings will also include monoeducational formats, as research in gender-sensitive education suggests that such settings can offer specific advantages in initiatives aimed at empowering girls and young women in STEM.

2.1 Laser Cutting

Laser cutters enable the cutting and engraving of various materials such as cardboard, felt, or wood using focused laser light. This technology allows for a broad range of applications, including decorative wall art, keychains, modular figures, smartphone stands, and customized storage solutions (***Fig. 1***).

During the planning phase of each workshop, the facilitators coordinate closely with the accompanying teacher or group leader to assess the participants' prior knowledge and learning context, allowing the content and depth of the workshop to be appropriately adapted. Depending on the pre-existing knowledge of the participants, the workshops deal with an introduction to the properties of light and the basic working principles of lasers at different levels of detail. Participant are further introduced into standard vector graphics software packages, like e.g. Inkscape. Although often unfamiliar to

participants and initially perceived as complex due to its wide range of functions, Inkscape has proven to be a highly suitable and versatile tool for educational purposes.

We are giving large room to our participants concerning the design of the objects, as their creativity and individual interests should be stimulated. While the workshop facilitators may define the material or a general object type - for example, felt keychains - individual ideas and creative choices are strongly encouraged. Providing a small number of example objects has proven helpful in supporting participants' creative processes.

From a technical perspective, potential sources of error are limited and manageable. Participants learn, for instance, that cutting and engraving paths must be defined using different colors, that material thickness must be considered when designing interlocking parts, and that all components of an object must be properly connected. Due to the relatively fast execution of the laser cutting process, minor failures - such as incomplete cuts or overly deep engraving - can be quickly identified and resolved by jointly adjusting machine parameters. This iterative fine-tuning provides an opportunity to explain how different materials and likewise different colors of the same material, absorb blue laser light to varying degrees, directly linking practical experience to underlying physical principles. Since all vector graphic files are checked by the workshop facilitators before production, virtually every single participant is guaranteed a successful outcome and can take their own creations home.

From an educational perspective, laser cutting combines visual design, spatial reasoning, and basic concepts of optics and materials science while providing immediate and tangible feedback. The opportunity to collaboratively correct small errors reinforces learning as an iterative and exploratory process rather than a one-time attempt. The high likelihood of successful outcomes supports positive mastery experiences and learner self-efficacy, particularly for participants with little prior technical experience. The emphasis on individual design decisions further promotes autonomy and creative agency.

Fig. 1: f. l. t. r.: laser cutting during the Maker Fair in Hannover, combined school workshop to build a city model, results from students.

2.2 3D Printing

Although 3D printers are increasingly common in schools and private households, many children have never transformed their own ideas into a physical 3D-printed object. The first step in this creative process is creating a digital 3D model. While numerous complex software solutions exist, we are utilizing the web-based, free software Tinkercad to be particularly well suited for educational workshops. Tinkercad allows instructors to create class accounts, enabling access to all student designs. The software's current intuitive interface requires only minimal instruction and is very intuitive for users at various ages and qualification levels (*Fig. 2*).

Since 3D printing itself is time-intensive, we need to predefine the overall dimensions of the objects in our workshops. Within these constraints and a given thematic framework - such as jewelry, pendants, or architectural models - participants are free to implement their own ideas. Workshop facilitators occasionally need to point out practical limitations, for example regarding very fine structures or the fact that multi-colored digital designs will still be printed in a single color. Despite these constraints, participants are able to achieve tangible results quickly, and enthusiasm is often so high that many wish to design and print additional objects. Depending on the specific participants and their level of previous knowledge, our workshops also include short presentations on industrial and research-based 3D printing methods, highlighting the broader relevance and potential of the acquired skills.

3D printing fosters spatial imagination and abstract-to-concrete thinking by translating digital designs into physical objects. The iterative nature of the design and fabrication process frames learning as

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problem-solving rather than a linear task. By balancing predefined constraints with creative freedom, the workshops support sustained engagement among diverse learners.

Fig. 2: f. l. t. r.: 3D printing workshop at Lichtwerkstatt, two girls during 3D designing with TinkerCAD, results from 3D printing workshops.

2.3 Embroidery Machines

In contrast to laser cutters and 3D printers, embroidery machines are more strongly associated with traditional gender stereotypes. In practice, we observe that interest among girls is often higher than among boys, although this does not apply universally.

Two different software tools are used, depending on the specific focus of each workshop. Turtlestitch, a free web-based platform, enables participants to create embroidery patterns through block-based programming similar to Scratch. Ink/Stitch, an extension for Inkscape, is primarily used for lettering and more detailed embroidery designs.

Turtlestitch combines textile design with introductory programming concepts. For participants without prior programming experience, the concept of an algorithm is introduced using everyday analogies, such as a cooking recipe. In the software, a small turtle moves according to programmed commands, leaving a trace that later is converted into an embroidered geometric pattern. This allows participants to easily create patterns and structures using lines and arcs. Either a basic algorithm can be provided and modified, or a general design goal - such as e.g. creating a pattern of three stars - can be defined. An element of surprise plays an important motivational role, as participants often reach a point where the outcome exceeds their ability to mentally visualize the result, prompting an iterative trial-and-error approach. The resulting patterns can be embroidered onto fabric or stitched onto cardboard to create greeting cards.

Ink/Stitch workshops require a basic introduction to Inkscape before focusing on the specific embroidery functions. For this reason, combined workshops often start with laser cutting and subsequently introduce Ink/Stitch. Participants learn about different stitch types - running stitch, fill stitch, and satin stitch. While many children prefer embroidering pre-existing images, converting raster images into suitable vector files is time-consuming. Therefore, we encourage our participants either to design their own motifs or to use simple, freely available vector graphics such as animal silhouettes or one-line art. Finished designs can be produced as patches or embroidered directly onto bags, cushion covers, or similar textile items.

Regardless of the software used, the introduction to the embroidery machine itself offers a valuable technical learning opportunity, particularly regarding the interaction between upper and lower threads - a mechanism unfamiliar to many participants.

The embroidery workshops bridge textile design and computational thinking by introducing algorithmic concepts through block-based programming (**Fig. 3**). The low-threshold programming approach conveys sequencing and iteration while reducing cognitive barriers. An element of unpredictability encourages experimentation and reframes errors as part of the creative process.

Fig. 3: f. l. t. r.: Code, simulation and result from Turtlestitch, girls during stitching with embroidery machine and designing in Inkstitch, results from a summer camp.

2.4 Combined Workshops

Due to the limited number of available hardware resources (typically two to five workstations), workshops are organized in rotating small groups using different devices simultaneously. One successful example is a collaborative "city project" implemented as a group puzzle. Here, each base group was tasked with designing two hexagonal city tiles. Expert groups worked with different tools: a CNC milling machine to produce the base tiles and carve roads or rivers, 3D printers to create buildings, and a laser cutter to produce trees, bushes, signs, and similar elements. Each expert group received an introduction to its respective tool and software before starting the fabrication process. Thanks to standardized dimensions for the hexagons and road widths, all components could be assembled into a large, coherent city model. The final result was met with visible pride and a strong sense of collective achievement among the participants.

Such combined workshop formats promote collaborative problem-solving and peer learning through distributed expertise across different technologies within the groups. Working toward a shared final product strengthens social learning and reinforces a sense of collective achievement. This workshop structure mirrors interdisciplinary practices common in STEM-related fields.

Across all workshop formats, recurring educational principles include learner autonomy, iterative design processes, error-friendly learning environments, and the creation of tangible, personally meaningful artifacts. Together, these principles support motivation, self-efficacy, and sustained engagement in STEM learning, particularly among girls and young women.

3. Role Models

A second key element of the *Hands on! STEM Makerspace* project on the conceptual is the integration of role models - women who are enthusiastic about STEM subjects, regardless of whether they are currently studying, completing vocational training, pursuing a doctorate, or have been working in the private sector in STEM fields. While this element is still in the early stages of implementation, the project is currently focusing on making these role models visible and creating formats that enable direct, personalized interaction with participant groups. Through these formats, we aim to challenge stereotypes, open up new perspectives, foster self-efficacy, and address concrete questions related to educational pathways and careers in STEM.

As part of the preparation for role model workshops, a role model gallery was created on the project's website. The gallery currently features more than 30 women who briefly share their enthusiasm for STEM, explain their career choices, and reflect on obstacles they have encountered and the strategies they developed to overcome them. In doing so, the gallery offers insight into the diversity of life paths and professional biographies of women in STEM. The gallery is publicly accessible online (www.acp.uni-jena.de/role-model-gallery) and is continuously being expanded.

4. Conclusion

The workshop formats developed within the *Hands on! STEM Makerspace* project cover a broad spectrum, ranging from school-based workshops to expert-level sessions at large public events. For each target group, we strive to identify appropriate themes and motivational approaches. Across all more than 40 workshops conducted to date, a consistent pattern has emerged: the joy of making - designing an idea independently and transforming it into a tangible product - helps participants overcome fear of failure and self-doubt.

Especially in school workshops, a frequently expressed sentiment among participants is: *"It was nice that we could create something creatively ourselves."* Rather than following rigid instructions or predefined outcomes, participants are encouraged to develop their own ideas and designs. While some initially struggle with this open-ended approach, as it differs from typical school experiences, they ultimately gain confidence in their creative and technical abilities.

Participants experience that operating digital design software and fabrication technologies is manageable and accessible, regardless of gender. In parallel to the creative workshop formats, the project includes dedicated role model workshops as a separate intervention. The element provides opportunities for direct exchange with women in STEM and offer counter-stereotypical insights into educational and career pathways. Taken together, the creative workshops and the role model formats address different but complementary dimensions of motivation and self-efficacy, contributing to a broader sense of belonging in STEM fields among girls and young women.

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