New Feature!

STEM SHOWCASE SECOND LOOK

This feature shines a spotlight on breakthrough best practices, clever methodologies, and game-changing approaches by returning them to the public eye.

The NTLS Microscope Prototyping System

BY DEBRA SHAPIRO, DTE, JO WATTS, GLEN BULL, AND N. RICH NGUYEN

The National Technology Leadership Society (NTLS) is a coalition of twelve national educational technology associations and was established to advance effective use of technology for teaching and learning. The International Technology and Engineering Educators Association (ITEEA) is a founding member.

The *NTLS 3D-Printed Microscope* is part of a broader initiative aimed at supporting the effective use of school makerspaces for science and engineering education. This NTLS initiative includes the establishment of an open-source peer-reviewed Educational CAD Model Library (*www.CADLibrary.org*). A key goal of the project is to help students develop a deeper understanding of scientific concepts by designing and fabricating scientific tools and instruments. This process can encourage creativity and strengthen problem-solving skills (Ferretti, 2019). The components of the NTLS Microscope and associated instructional resources are available in the CAD Library (Watts & Bull, 2025).

The NTLS 3D-printed microscope builds on a number of prior efforts. Vos, Blesa, and Betz (2021) developed a LEGO-based microscope that could be constructed by middle school students with the goal of facilitating understanding of the underlying principles of microscopes. Tadrous (2021) developed an open-source 3D-printed microscope with the goal of providing an affordable tool for field work. The OpenFlexure Microscope is an open source 3D-printed microscope widely used in scientific and medical settings that was designed to teach university students fundamental microscopy principles while still providing commercial-quality imaging (Collins et al., 2020).

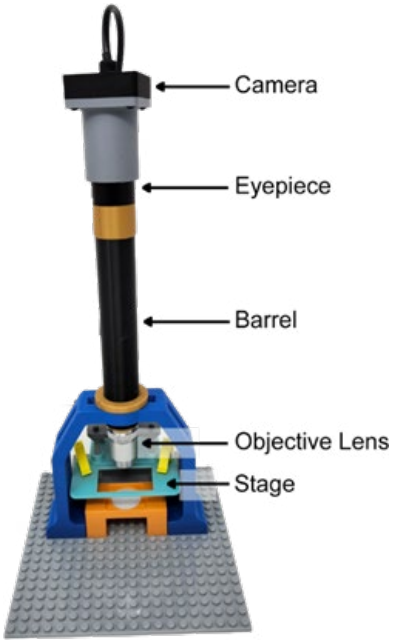

Figure 1. The NTLS 3D-printed Microscope.

The NTLS microscope builds on foundational work by the Open Flexure team with a 3D-printed design developed specifically for K-12 students. The NTLS Microscope is a microscope design prototyping system intended to provide students with foundational skills that will enable them to design their own enhancements that build on the basic framework provided. The initial development of the NTLS Microscope took place through a collaboration between the Make to Learn Laboratory at the University of Virginia and engineering students in Virginia schools (Berry et al., 2024).

The images obtained can approximate the images from a $400 commercial microscope designed for school science classes. This is in part through the use of commercially manufactured compound lenses similar to those found in school microscopes. A school microscope has two lenses:

1. an objective lens that is placed near the object being viewed, and
2. an eyepiece that is placed at the other end of the microscope barrel.

While costs fluctuate over time, we were able to purchase these two lenses available as replacement

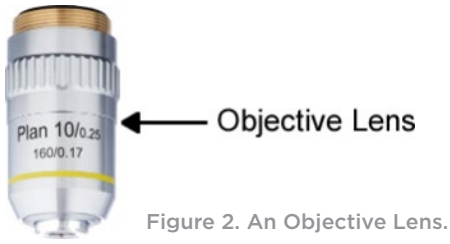

Figure 2. An Objective Lens.

Figure 3. Objective Lens Attached to 3D-printed Barrel.

Figure 4. An Eyepiece Lens.

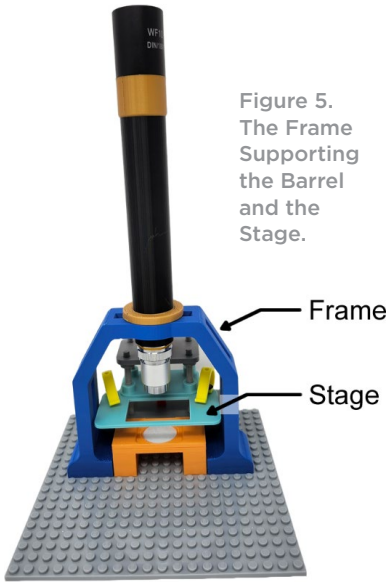

Figure 5. The Frame Supporting the Barrel and the Stage.

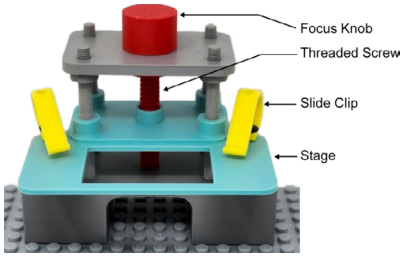

Figure 6. The Focus Mechanism (Threaded Screw and Knob).

parts for a $400 school microscope for about $40. Therefore, in this particular instance, the two lenses cost about ten percent of the entire cost of the commercial microscope (AmScope, 2025).

The strategy of purchasing the optical elements of the microscope and 3D-printing the mechanical components like the barrel and focus mechanism made it possible to fabricate a microscope for considerable savings in comparison with its commercial counterpart. The 3D-printed version does not have all the features of the commercial microscope. For example, the commercial microscope uses planetary gears to create a coarse focus and a fine focus. To facilitate ease of replication in school settings, the basic NTLS microscope only has a coarse focus.

The NTLS microscope is designed as a microscope prototyping system that provides STEM students with experience in fabrication of microscopes. As students gain experience, additional elements such as a fine focus mechanism can be incorporated into the design.

Components of a Microscope

Objective Lens. The objective lens is the heart of an optical microscope. This is the lens that is placed near the *object* being viewed – therefore the term *objective* lens. An objective lens that magnifies the image by ten times is said to have a 10x magnification.

The objective lens is screwed into the barrel of the microscope. 3D-printed light baffles inside the barrel of the NTLS microscope play an important role in reducing light reflections (Freniere, 1981).

Eyepiece. An eyepiece at the other end of the barrel increases the magnification. The total magnification of the microscope is obtained by multiplying the magnification of the objective lens by the magnification of the eyepiece. For example, if the objective lens has a magnification of 40x and the eyepiece has a magnification of 10x, the magnification of the microscope will be 400x.

Stage. A stage (shown in Figure 5) supports the slide that contains the specimen being viewed. A frame (Figure 5) supports the barrel and lens pieces, positioning the objective lens directly above the stage.

Focus Mechanism. A focus mechanism changes the distance between the stage and the objective lens to adjust the focus. The focus mechanism consists of a threaded screw and focus knob (shown Figure 6) that raises and lowers the stage. Slide clips (Figure 6) hold the slide in place on the stage.

The base model NTLS Microscope was designed for ease of replication in school and community makerspaces. There is a tradeoff between simplicity and features. An enhanced focus module incorporates both a fine and a coarse focus mechanism. As students gain more experience, they can fabricate more complex versions that build on the basic model.

Illumination. An LED light beneath the stage shines through the slide to provide a source of illumination. A light diffuser (shown in Figure 7) reduces glare to produce an even illumination of the slide.

Figure 7. Illumination (LED Light and Battery).

Figure 8. Digital Camera.

Digital Imaging. A camera housing can be used to mount a USB camera to the NTLS Microscope. This makes it possible to capture a digital image and facilitates sharing.

Because the optical lenses employed in the 3D-printed microscope are comparable to the optical lenses used in commercial microscopes used in schools, the images obtained are also comparable. The images below depict a stained onionskin at 40x, 100x, and 400x magnification using the NTLS Microscope.

The series of slides below depicts the same levels of magnification for a protozoa.

A comparison of the images captured with the NTLS Microscope and a commercial microscope (a Swift Model 350t) purchased for $400 at 400x magnification demonstrates that the results are comparable.

The commercial microscope has a number of features such as fine focus mechanism that employs planetary gears and a revolving turret that makes it easier to switch between magnifications. Therefore, there are advantages to using a commercial microscope when funds are available. The NTLS Microscope Prototyping System can be useful in enabling students to learn underlying principles of microscopy and in conserving scarce resources.

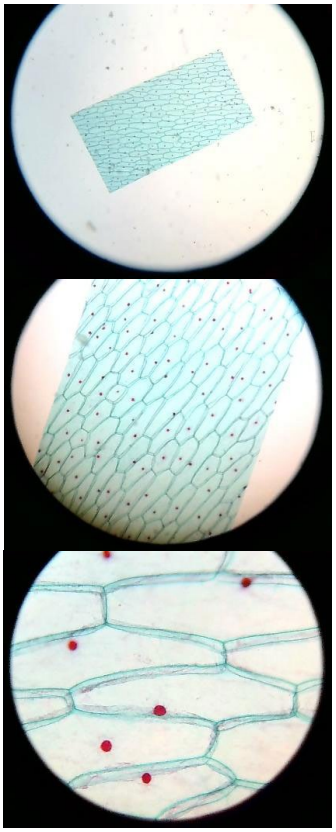

Figure 9. Onionskin at 40x, 100x, and 400x.

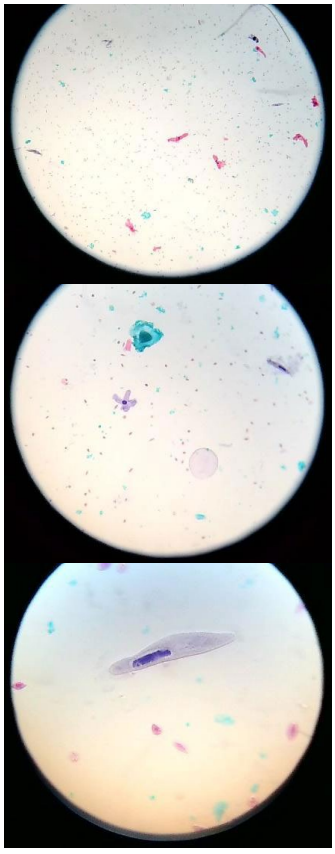

Figure 10. Protozoa at 40x, 100x, and 400x.

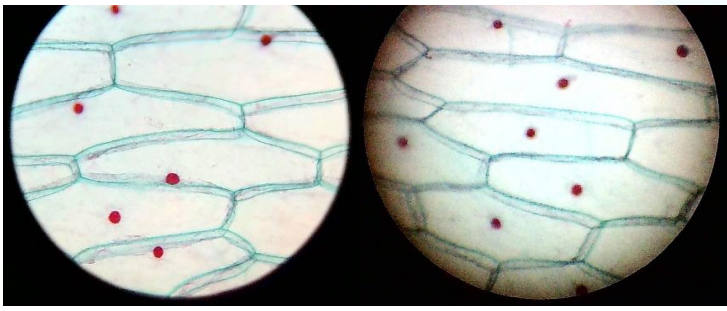

Figure 11. NTLS Microscope (left) and Commerical School Microscope (Right).

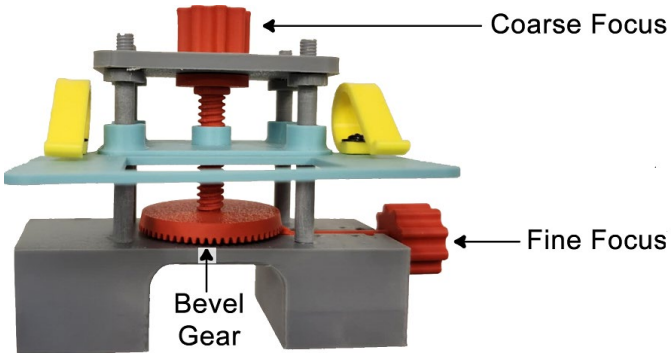

Figure 12. Addition of a Fine Focus Adjustment.

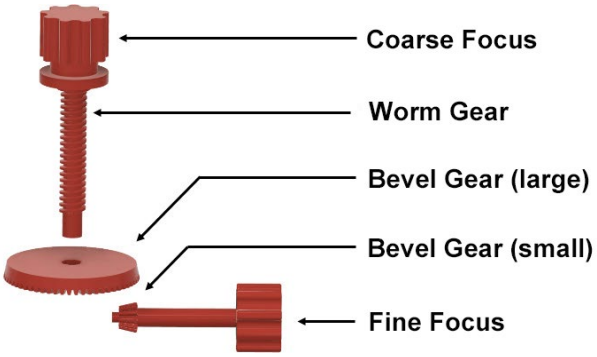

Figure 13. The Two Bevel Gears Are at Right Angles to One Another.

A Framework for Collaboration and Design

As these examples suggest, the basic NTLS Microscope provides a framework for a variety of modifications and extensions.

CAD FILES

The basic design has been published in the NTLS Educational CAD Model Library:

https://cadlibrary.org/science

The CAD files can be downloaded so that the design can be replicated and/or modified. Future modifications and enhancements by students will be published as updates in the CAD Library, making them available to the broader community.

EXTENSIONS

The base design has a coarse focus mechanism consisting of a threaded rod. This mechanism is straightforward to fabricate and is easy for novices to assemble. The basic microscope can be revised through the replacement of this mechanism with a *Fine Focus* module. This module retains the coarse focus mechanism and adds fine focus control.

The *Fine Focus* control consists of a bevel gear attached to the base of the worm gear. A second bevel gear at the end of a rod is attached to the fine focus knob. The second bevel gear meshes with the first bevel gear at the end of the vertical worm gear.

The benefits of finer control over focus come at the expense of increased requirements for precision of fabrication and assembly. Commercial microscopes often use planetary gears to achieve fine focus, which would require even greater precision in fabrication. The specific design employed in the 3D-printed microscope depends on the experience of the student and the needs of the school.

ONLINE COMMUNITIES FOR SHARING

Online communities play a critical role in the successful use of open hardware designs in universities (Mies et al., 2020). Online communities could potentially contribute to the use of open hardware designs in K-12 schools and diverse communities. This commitment is reflected by the choice of project participants to engage, at various times, with the *Foldscope* and *OpenFlexture* microscopes, both of which feature robust online communities of engagement (Foldscope, n.d.; OpenFlexure Project, n.d.). A computer science student at the University of Virginia is developing an application to enable students to share and compare specimens.

Computer-Controlled Microscope

Microscopes in research settings often incorporate features such as computer control and artificial intelligence. The University of Virginia Department of Computer Science is collaborating on development of the NTLS microscope to add these features as an option for incorporation by experienced K-12 students.

AUTOMATED FOCUS

The hardware used to implement automated focus is an enhancement of the NTLS Fine Focus module that connects a stepper motor to the shaft of the fine focus control.

The image of a specimen on a slide is captured by the microscope camera module. An algorithm imple-

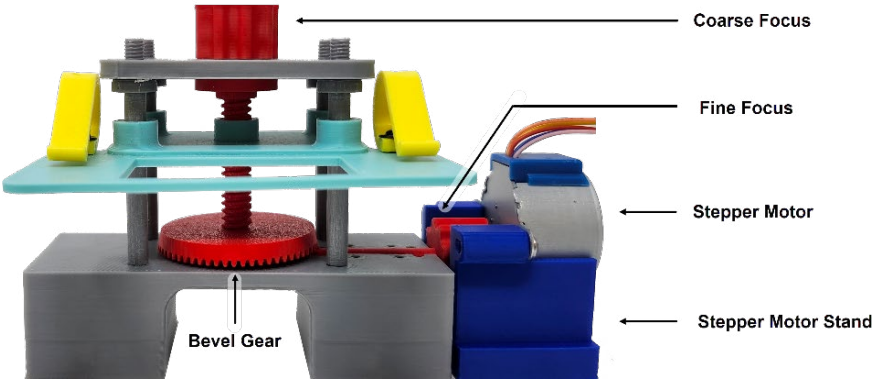

Figure 14. Computer Control of the Focus Mechanism via a Stepper Motor.

mented in Snap*!* uses edge detection to determine when the image is in focus.

Snap*!* is an educational language developed at the University of California, Berkeley to support the Advanced Placement (AP) curriculum, the *Beauty and Joy of Computing*. The lead developers of this curriculum, Brian Harvey and Dan Garcia, were recognized in 2025 with the Association for Computing Machinery (ACM) Karlstrom Outstanding Educator Award for this accomplishment.

The NTLS Microscope builds on this foundation through use of Snap*!* as the framework for computer control of the microscope. The intent is to make the implementation transparent and understandable so that students can see, understand, and modify the software.

The Snap*!* program determines the direction to turn the focus knob. This information is communicated to a program on the microcontroller connected to the focus control. This program, implemented in MicroBlocks, uses the microcontroller to turn the focus control in the appropriate direction. Based on the results, the Snap*!* program makes appropriate adjustments until the slide is in focus.

A high school student working with CS faculty and students developed a basic proof-of-concept implementation to explore the feasibility of implementation by K-12 students. The basic implementation, available in the CAD Library, provides a foundation that other students can modify and extend.

ARTIFICIAL INTELLIGENCE

Once an image has been captured via automated microscopy, artificial intelligence (AI) features can be used to analyze and classify images (Zhang et al, 2022). A team of computer science students at the University of Virginia is working to develop AI features that can be used in conjunction with the computer-controlled version of the NTLS microscope. This application is under development and will support automated microscopy in which samples are analyzed through the use of artificial intelligence to support comparisons of specimens collected across different biomes in different geographic regions.

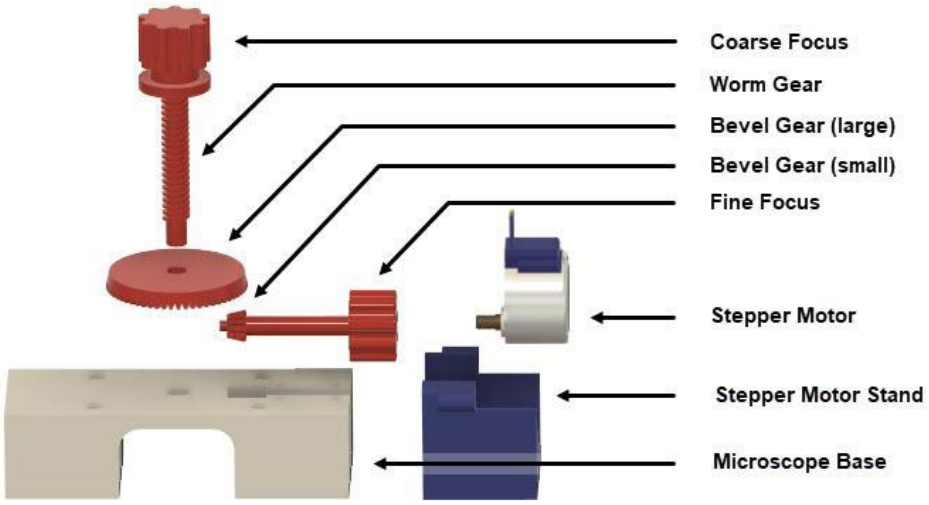

Figure 15. Exploded Diagram of the Computer-Controlled Focus Enhancement.

We are integrating the Snap*!* program used to acquire images with iNaturalist. This is a widely used platform with an extensive database of crowd-sourced specimens. Linking the NTLS Microscope to the iNaturalist application interface (API) will enable students to upload and share microscope images from connected devices. This will allow students to geo-tag specimens and receive both community and AI support for identification of specimens.

The long-term goal is real-time, collaborative learning in which students contribute to classroom projects as well as to broader scientific communities. Teachers can guide students in creating customized observation projects, utilizing interactive biodiversity maps, and developing inquiry-based lessons centered on ecological or evolutionary questions. Furthermore, by incorporating computer vision tools that guide students in identification of species without providing direct answers, we plan to encourage critical-thinking and reasoning skills. These features, coupled with gamified interfaces, multiple-choice quizzes, and scaffolded prompts, will position the NTLS Microscope as a platform for integrating hands-on STEM learning with authentic scientific inquiry. The open source application, developed in Snap!, will enable students and teachers to examine and modify the software to create their own extensions and enhancements.

Summary

The 3D-printed microscope project was designed as part of a larger initiative to make teacher-validated and tested CAD models available to the educational community via the NTLS Educational CAD Library. A primary potential benefit is an improved understanding of microscope design and fabrication by technology and engineering students. The ability to subsequently use these scientific tools to enhance science classes is an added benefit.

This also can enable schools to extend the use of scarce resources.

Broken microscopes are sometimes set aside in school storerooms because the cost of shipping and repair can exceed the replacement cost. In those cases, the lens can be removed and used as the lens for an NTLS Microscope. A further advantage is that if a 3D-printed microscope breaks, a replacement part can be printed.

ITEEA has played a leading role in this initiative, working in conjunction with other national education associations who are members of NTLS. The educational materials and resources developed through these collaborations will be made available to ITEEA members through publication in the Educational CAD Model Library (CAD Library). The CAD Library is an open-source peer-reviewed repository of educational CAD models jointly developed by ITEEA in collaboration with peer associations affiliated with the National Technology Leadership Society (NTLS). Ultimately the goal is to provide technology and engineering students participating in this curriculum with authentic design and fabrication experiences that directly benefit the student as well as their school.

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Debra Shapiro is a Technology and Engineering Educator at Forest Glen Middle School in Suffolk Virginia and past-president of ITEEA. She can be reached at dshapiro.iteea@gmail.com.

Jo Watts is manager of the Make to Learn Laboratory at the University of Virginia.

Glen Bull is a Professor of Education in the School of Education and Human Development at the University of Virginia.

N. Rich Nguyen is an Associate Professor of Computer Science at the University of Virginia.