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An Inexpensive Programmable Dual-Syringe Pump for the Chemistry Laboratory

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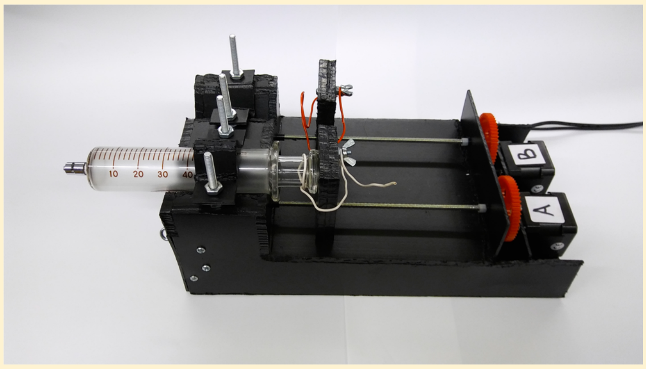
S *Supporting Information*

ABSTRACT: A programmable dual-syringe pump was constructed from inexpensive materials. The syringe pump can accommodate two syringes of the same or different size without any modification of the platform. Unlike other reported open-source syringe pumps, the syringes can be dispensed independently of one another without modification. The total cost of the syringe pump is roughly \$100 including the microcontroller and roughly \$60 without.



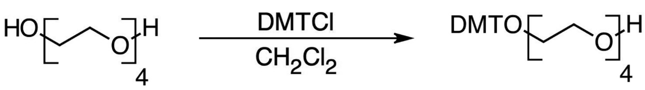
KEYWORDS: *General Public, Interdisciplinary/Multidisciplinary, Laboratory Instruction, Hands-On Learning/Manipulatives, Laboratory Equipment/Apparatus*

INTRODUCTION

Chemical educators are resourceful when equipment critical to teaching and learning is, for one reason or another, unavailable. The *Journal of Chemical Education* (*JCE*) has always been a conduit though which chemists can share their ingenuity in this regard. Recent examples include a magnetic stirrer, a light board projection system, and an epifluorescence microscope.[1−3]

In the course of a summer research project, we needed to prepare (4,4′-dimethoxytrityl)tetraethylene glycol from commercially available tetraethylene glycol (Scheme 1). The literature preparation called for the slow addition of 4,4′-dimethoxytrityl chloride (DMTCl) by syringe pump over 16 h under inert, anhydrous reaction conditions.[4] Without access to a commercial syringe pump, we attempted the dropwise addition of the reagent using a pressure-equalizing dropping funnel. As one might expect, this 16 h addition was extraordinarily difficult to regulate using the funnel, either finishing too soon or not at all (i.e., the addition would stop at some point during the night.) After several attempts at the reaction using a dropping funnel, the student took it upon himself to design and construct a syringe pump using resources he could acquire locally or online.

Scheme 1. Synthesis of (4,4′-Dimethoxytrityl)tetraethylene Glycol



Commercial programmable syringe pumps are expensive and may be cost-prohibitive for many teaching/research laboratories. Consequently, a literature review shows that a number of low-cost, DIY/open-source syringe pumps have recently been reported (as well as a not-so-recent report in *JCE* of a motor-driven syringe derived from a variable-speed strip-chart recorder), including several pumps with parts fabricated with three-dimensional (3D) printers.[5−8] Herein is described a low-cost, programmable dual-syringe pump for the chemistry laboratory that can be constructed *with or without* parts fabricated using a 3D printer.

SYRINGE PUMP DESIGN

The core components of a syringe pump include a lead screw to depress the syringe plunger, a motor to drive the lead screw, and a motor drive controller. Commercial models use a specially designed lead screw and smooth rods with linear bearings. These design features increase the accuracy and reproducibility of the dispenses by reducing any pulsing that occurs as fluids are dispensed. Pulsing happens when slack forms in the lead screw, interrupting the dispensing of fluid. Slack can form in the lead screw as a result of unintentional shifting/rotation of the linear object and/or bending of the lead screw. The specially designed lead screw used in commercial syringe pumps (as well as computerized numerical control (CNC) machines and linear actuators) decreases this slack

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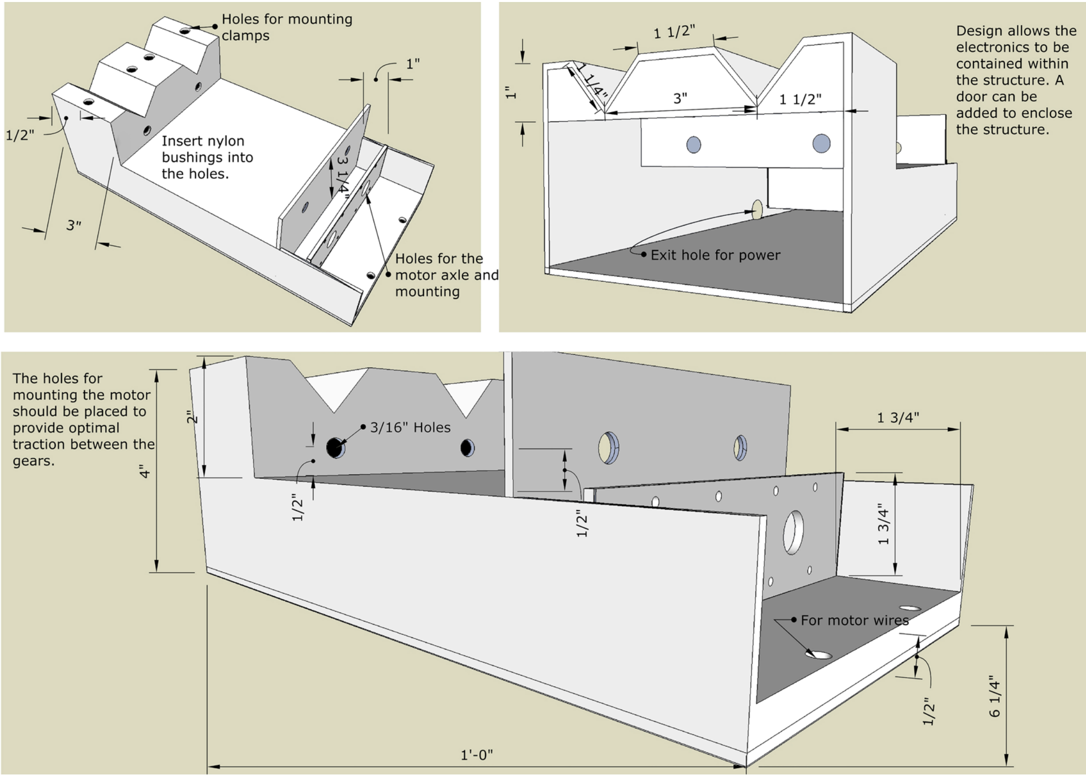

Figure 1. Syringe pump platform schematic.

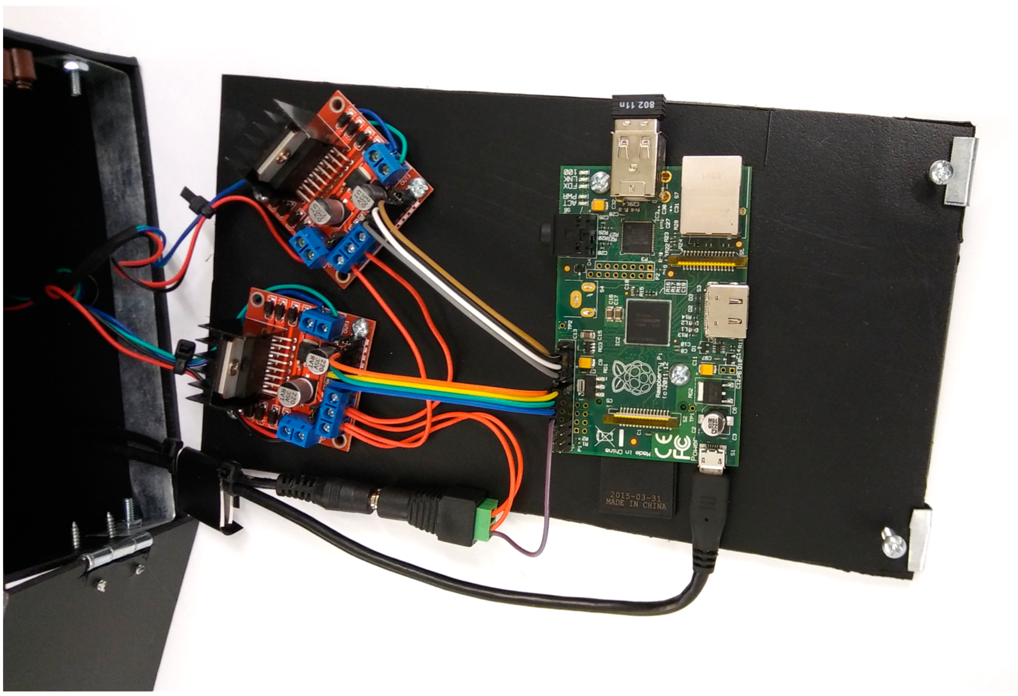

Figure 2. Syringe pump−Raspberry Pi interface.

because the threading of the screw increases the contact surface area between the linear object and the lead screw. The smooth rods decrease slack in the lead screw by providing additional structural support. As with other instrumentation, the increased accuracy and reproducibility increase the cost of the equipment.

Our design attempts to balance cost against accuracy and reproducibility while providing functionality that other open-source syringe pumps do not have. The syringe pump platform is constructed from 1/8″ high-density polyethylene (HDPE) (Figure 1). HDPE can be welded together using a soldering iron and provides some chemical resistance. (The v-clamps that secure the syringes to the platform (shown in the abstract graphic) can be 3D-printed; see file S1 and file S4 in the Supporting Information.) The lead screws are threaded rods

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driven by 12 V/0.4 A NEMA 17 stepper motors and L298N dual H-bridge drivers and controlled by a Raspberry Pi running Raspbian OS. The syringe pump can accommodate two syringes of the same or different size without any modification of the platform. Unlike other reported open-source syringe pumps, the syringes can be dispensed independently of one another without modification. The total cost of the syringe pump is roughly \$100 including the microcontroller and roughly \$60 without.

■ SYRINGE PUMP CONTROL

The syringe pump is controlled by a Raspberry Pi. The Raspberry Pi interfaces with the stepper motors via driver boards, as shown in Figure 2. (A wiring schematic can be found in file S1.) The software program to control the syringe pump was developed in Python, a programming language that emphasizes simple, readable syntax. The code is specific to a syringe and can be saved for subsequent use. For each syringe, the user enters the capacity of the syringe (in mL), the length of the syringe from 0 mL to the maximum volume (in mm), and a name for the syringe (e.g., "50 mL syringe"). To dispense, the user enters the name of the syringe to be used, the volume to dispense (in mL), and the time over which the dispense is to be made (in h). With these variables, the program calculates the number of steps the motor must take (based on steps per revolution of the motor, gear ratio, and threads per inch of the lead screw) and divides the time to dispense over these steps.

■ SYRINGE PUMP PERFORMANCE

The accuracy and reproducibility of the syringe pump was assessed using gravimetric tests of repeated dispenses onto an analytical balance (Mettler AE100) (see file S2; environmental factors were not taken into account). The accuracy and precision of 1 and 0.1 mL dispenses using 50, 10, and 1 mL glass syringes are shown in Table 1.

Table 1. Accuracy and Precision of Syringe Pump Dispenses Using Various Glass Syringes

Syringe Volume (mL)	Dispense Volume (mL)	Relative Error (%)[a]	Relative Average Deviation (%)[a]
50	1.00	0.56	1.7
	0.100	4.4	15
10	1.00	1.6	4.2
	0.100	−5.1	9.0
1	0.100	0.20	4.4

[a] $N = 10$; The p values derived from two-tailed t tests (actual dispense volumes vs theoretical dispense volumes) are all greater than 0.05.

Overall, the syringe pump performance was independent of the glass syringe used and/or the dispense volume (the p values derived from two-tailed t tests (actual dispense volumes versus theoretical dispense volumes) are all greater than 0.05). Although the percent relative errors indicate that the accuracy of the dispenses is comparable to that of other open-source pumps,[5] the percent relative average deviations among the dispenses indicates, on the whole, a lack of precision in repeated dispenses. Without specially designed lead screws and smooth rods with linear bearings, it is not unexpected that our design would show evidence of pulsing. Although the lack of precision might compromise the utility of the syringe pump for titration work, we have found the syringe pump to work without failure for controlled, overnight dispenses.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.6b00598.

S1: instructions for building the dual-syringe pump (PDF, DOCX)
S2: procedure used to determine syringe pump performance using gravimetric tests of repeated dispenses (PDF, DOCX)
S3: Raspberry Pi program files (ZIP)
S4: STL files to model and 3D-print the v-clamp (ZIP)

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Notes

The authors declare no competing financial interest.

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■ REFERENCES

(1) Guidote, A. M., Jr.; Pacot, G. M. M.; Cabacungan, P. M. Low-Cost Magnetic Stirrer from Recycled Computer Parts with Optional Hot Plate. *J. Chem. Educ.* **2015**, *92*, 102−105.
(2) Skibinski, E. S.; DeBenedetti, W. J. I.; Ortoll-Bloch, A. G.; Hines, M. A. A Blackboard for the 21st Century: An Inexpensive Light Board Projection System for Classroom Use. *J. Chem. Educ.* **2015**, *92*, 1754−1756.
(3) Stewart, C.; Giannini, J. Inexpensive, Open Source Epifluorescence Microscopes. *J. Chem. Educ.* **2016**, *93* (7), 1310−1315.
(4) Fiammengo, R.; Musílek, K.; Jäschke, A. Efficient Preparation of Organic Substrate—RNA Conjugates via in Vitro Transcription. *J. Am. Chem. Soc.* **2005**, *127*, 9271−9276.
(5) Wijnen, B.; Hunt, E. J.; Anzalone, G. C.; Pearce, J. M. Open-Source Syringe Pump Library. *PLoS One* **2014**, *9* (9), e107216.
(6) Patrick, W. Open source syringe pump. http://fab.cba.mit.edu/classes/863.13/people/wildebeest/projects/final/index.html (accessed October 2016).
(7) Connelly, B. Trying to make the worlds cheapest syringe pump/linear drive. http://www.billconnelly.net/?p=176 (accessed October 2016).
(8) Gawley, R. E.; Carlson, A. F. Conversion of a Variable-Speed Strip-Chart Recorder to a Motor-Driven Syringe. *J. Chem. Educ.* **1986**, *63* (6), 554.

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