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# Using Self-Efficacy Theory to Design Arduino Instruction for Novices: A Replication Study

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A replication study was conducted to determine the effectiveness of an instructional treatment based on self-efficacy theory when used with novice Arduino microcontroller users. Students ($n$ = 32) in an introductory university agricultural systems technology course participated in a lesson on Arduino microcontrollers, circuit breadboarding, and Arduino programming which included four hands-on practice tasks, designed to provide students with positive mastery, vicarious and social persuasion experiences. Next, students completed a laboratory activity and were provided additional opportunities for mastery, vicarious, and social persuasion experiences. The one-group pretest-posttest design indicated the instructional treatment had significant ($p < .001$) and large effects in increasing students' interest in Arduino, breadboarding self-efficacy, programming self-efficacy, and Arduino knowledge. These findings were consistent with the original study and provided additional evidence for self-efficacy theory as an effective model for developing instruction for novice Arduino users. Students' written comments provided additional insight concerning the instructional treatment.

**Keywords:** Arduino, novices, self-efficacy, teaching and learning

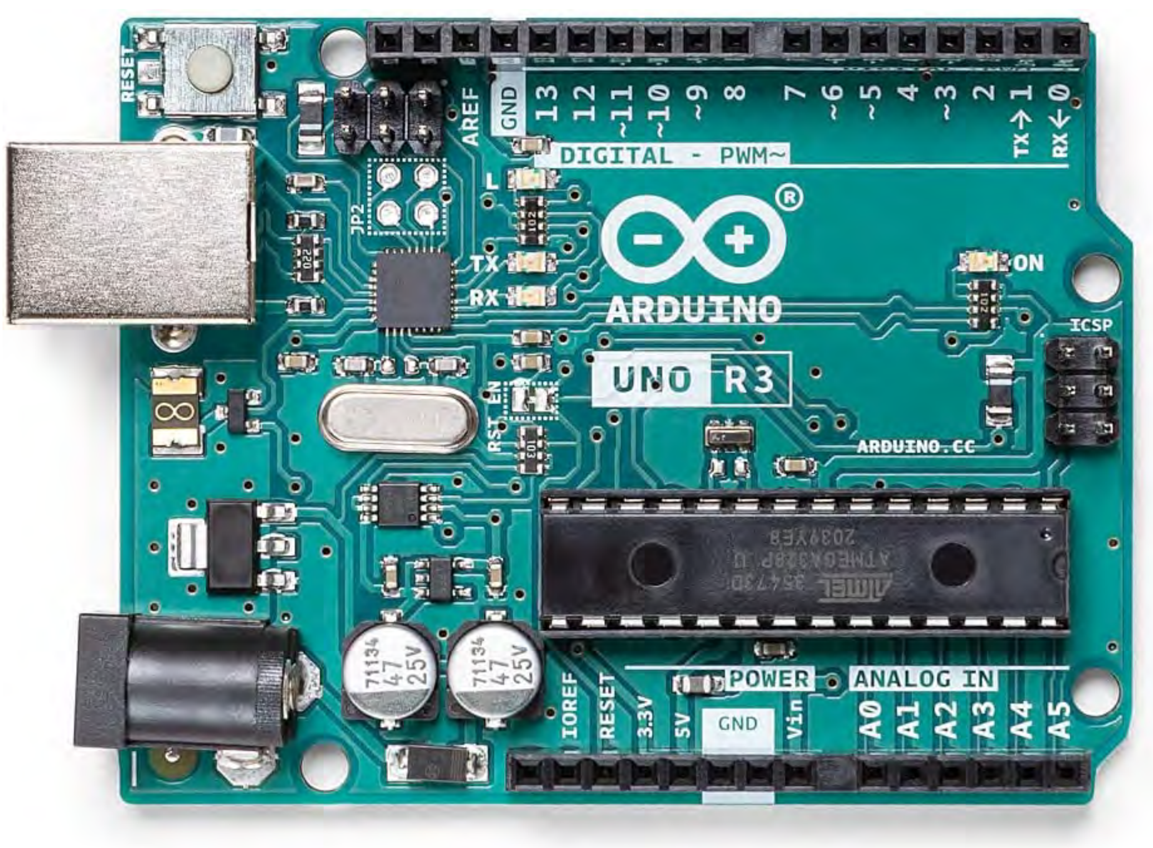
## Introduction

Microcontrollers are integrated circuit devices that contain a microprocessor, peripherals, and inputs and outputs in a small physical package (Keim, 2019). Microcontrollers are at the heart of embedded computing systems widely used in agricultural applications ranging from greenhouses (Liu, 2022) to field robots (Jude et al., 2022). Because microcontrollers are ubiquitous in monitoring and control systems (Darr et al., 2007), agriculture students should develop a basic understanding of microcontrollers as part of their undergraduate education (Hood, 2022). This is supported by Mercier (2015) who encouraged educators to prepare graduates for “related occupations that serve the . . . agricultural and food sciences disciplines” (p. 2), and by Stripling and Ricketts (2016) who indicated the need to identify methods, models, and programs to support career preparation for a scientific workforce in agriculture.

The Arduino UNO (Figure 1) is a programmable, open-source microcontroller widely used to teach microcontroller principles and programming (Al-Abad, 2017). According to Herger and Bodarky (2015), the Arduino UNO is a complete hardware and software package that can be used to teach both novice and advanced students.

**Figure 1**

*Arduino UNO Microcontroller*




Researchers have found that novice students experience difficulties in learning to work with Arduinos. The primary difficulties were related to breadboarding (constructing temporary) circuits and programming (DesPortes & DiSalvo, 2019; Sadler et al., 2017). Sadler et al. (2017) reported that, after instruction, only 36 of 68 (52.9%) students could successfully complete a simple breadboarding and Arduino programming task. Lane et al. (2002) noted that task failure was associated with decreased task self-efficacy, while Smith et al. (2006) found that failure at a specific academic task significantly decreased university students' task-related self-efficacy and their subsequent performance on that task relative to a control group. Ryan and Deci (2000) found that low self-efficacy in a particular subject was related to decreased student interest in studying the subject. Thus, novice students studying microcontrollers and microcontroller programming may fail at initial tasks, and, consequently, develop low self-efficacy and decreased interest in learning about microcontrollers and programming.

Recognizing this potential for student failure and the resultant lack of self-efficacy and decreased interest when studying microcontrollers and programming, Johnson et al. (2022) used Bandura's (1986) self-efficacy theory to develop an instructional treatment (lesson and laboratory activity) to teach circuit breadboarding and Arduino programming to novice students in introductory agricultural systems technology courses at two universities. The instructional treatment was evaluated on whether it increased students' Arduino interest, breadboarding self-efficacy, Arduino programming self-efficacy, and Arduino knowledge. In the pilot test at University A, the researchers reported significant ($p < .01$) and large (Cohen, 1988) increases in post-treatment measures of breadboarding self-efficacy and Arduino knowledge, but no significant ($p > .05$) increases in Arduino interest or programming self-efficacy. This was consistent with the lower project rubric scores for programming and the substantial (Davis, 1971) correlations ($r = .50$ to $.58$) between breadboarding and programming task performance and breadboarding self-efficacy, programming self-efficacy, and Arduino interest. Based on these results, the researchers revised the instructional treatment by incorporating four hands-on practice tasks into the lesson and re-tested the treatment at University B. The revised instructional treatment resulted in significant ($p < .001$) and large (Cohen, 1988) increases in posttest measures of students' Arduino interest, breadboarding self-efficacy, Arduino programming self-efficacy, and Arduino knowledge.

According to Bettis et al. (2016), replication of previous research is an essential cornerstone for "creating repeatable, cumulative knowledge" (p. 2193) in a discipline. Bettis et al. further stated "if studies of the same population differ in only the data sample but provide different results, the validity of these results may warrant further investigation" (p. 2195). Conversely, if a replication with the same population and a different data sample produces the same results, validity for that population is strengthened. Therefore, this study sought to replicate the Johnson et al. (2022) study using a different sample drawn from the same population at University A and using the same revised instructional treatment found to be effective at University B.

## Theoretical Framework

Johnson et al. (2022) used Bandura's (1986) self-efficacy theory, a component of Bandura's (1977) larger social cognitive learning theory, as the theoretical framework for developing their instructional treatment for novice Arduino users. Bandura (1986) defined self-efficacy as a person's confidence in their ability to perform a particular behavior or task. Individuals with high self-efficacy are confident in their ability to successfully complete the behavior or task while those with lower self-efficacy are less confident. Bandura (1986) posited that a person's self-efficacy for a particular behavior or task was influenced by three types of experiences: mastery, vicarious, and social persuasion. Mastery experiences have the strongest influence on self-efficacy and occur when an individual successfully accomplishes a behavior or task. Vicarious experiences have the second strongest influence on self-efficacy and occur when an individual sees someone they deem like themselves successfully accomplish a behavior or task. Finally, social persuasion experiences, the least powerful influence on self-efficacy, occur when a trusted person such as a teacher expresses confidence in the individual's ability to successfully complete the behavior or task.

In addition to mastery, vicarious, and social persuasion experiences, Bandura (1986) identified a fourth factor, physiological and emotional state, which affects self-efficacy. According to McKim and Velez (2016), physiological and emotional state refers to an individual's "internal state and emotions when considering or completing the task" (p. 74). Thus, an individual who approached a behavior or task in a relaxed manner would be expected to have a higher level of task-related self-efficacy than would an individual who approached the same task in a nervous or anxious emotional state.

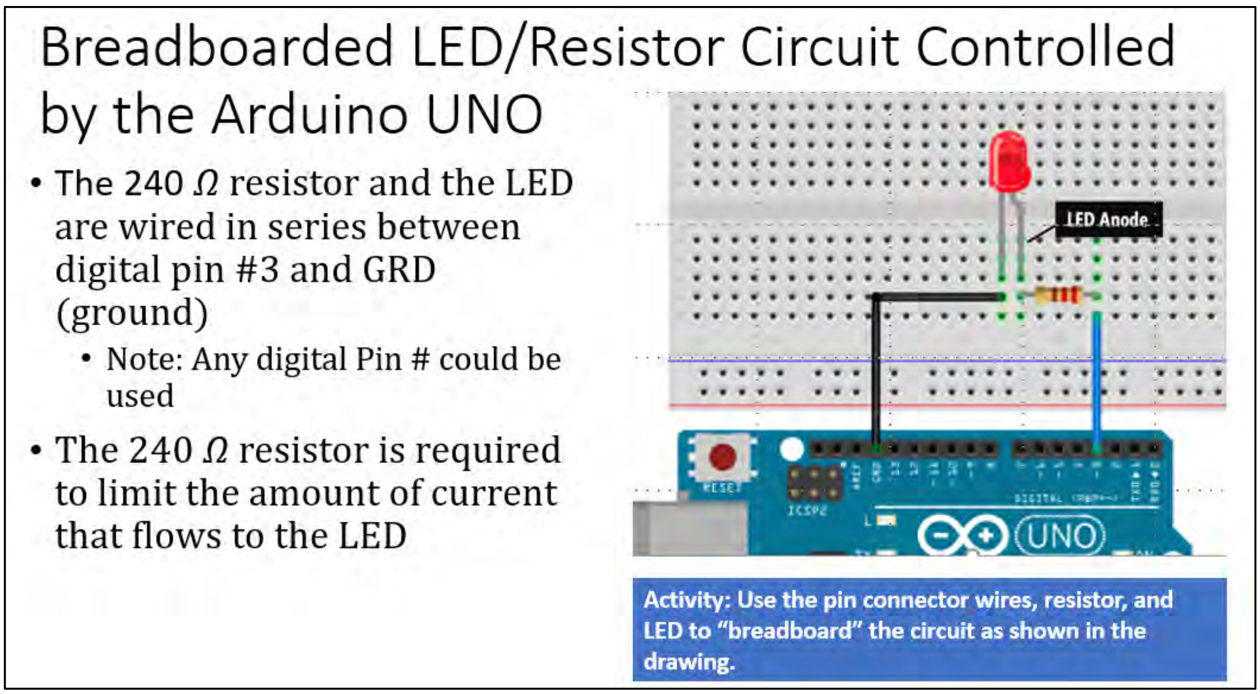
**Application of Self-Efficacy Theory in Instructional Design.** Self-efficacy is enhanced when learners approach a task in a relaxed state and have positive mastery, vicarious, and social persuasion experiences (Bandura, 1986; McKim & Velez, 2016). Thus, facilitating this relaxed approach and providing these positive experiences during the lesson and subsequent laboratory activity were a central focus in the original design of the instructional treatment (Johnson et al., 2022). This same focus and procedures, outlined below, were used in this replication.

**Lesson.** The 40-minute lesson was presented on the first day (Monday) using the same 12 PowerPoint slides developed by Johnson et al. (2022). The lesson was presented enthuastically in a confident, positive manner to promote a positive physiological and emotional state among the students. The instructor expressed confidence that students would enjoy learning circuit breadboarding and Arduino programming and would be successful in completing the laboratory activity.

To provide mastery, vicarious, and social persuasion experiences during the lecture, each pair of students received a package containing an Arduino UNO, pin connector wires, one 240-ohm resistor, one LED, and two paper copies of a mock-up of the Arduino Integrated Development (programming) Environment (IDE) for use during the four hands-on practice tasks incorporated into the lecture (Figure 2). The practice tasks were: (a) point to the primary components of the Arduino UNO, (b) identify resistors and the anode (+) and cathode (-) terminals of the LED, (c) breadboard a complete resistor-LED circuit between a specific digital pin and ground pin on the Arduino UNO, and (d) write an Arduino program (in pencil on the paper mockup of the Arduino IDE) to cause the LED to blink repeatedly with a 1-second delay. These were the same four practice activities used in the Johnson et al. (2022) study. Students were successfully guided through each practice activity (mastery experiences), the instructor publicly recognized students as they correctly completed each practice activity (vicarious experiences), and the instructor provided verbal statements of confidence that students could successfully complete each practice activity (social persuasion experiences). At the end of the lesson, three pairs of students were selected to bring their breadboarded circuits to the front of the room, enter their programs into the Arduino IDE on the classroom computer, download the programs to their Arduino UNO, and demonstrate the operating circuit to the class. All three circuits and programs worked (mastery and vicarious experiences) and the instructor expressed confidence that all the students' circuits and programs would work equally well (social persuasion experiences).

**Figure 2**

*Example Lesson Slide with Instructions for Hands-on Practice Task*



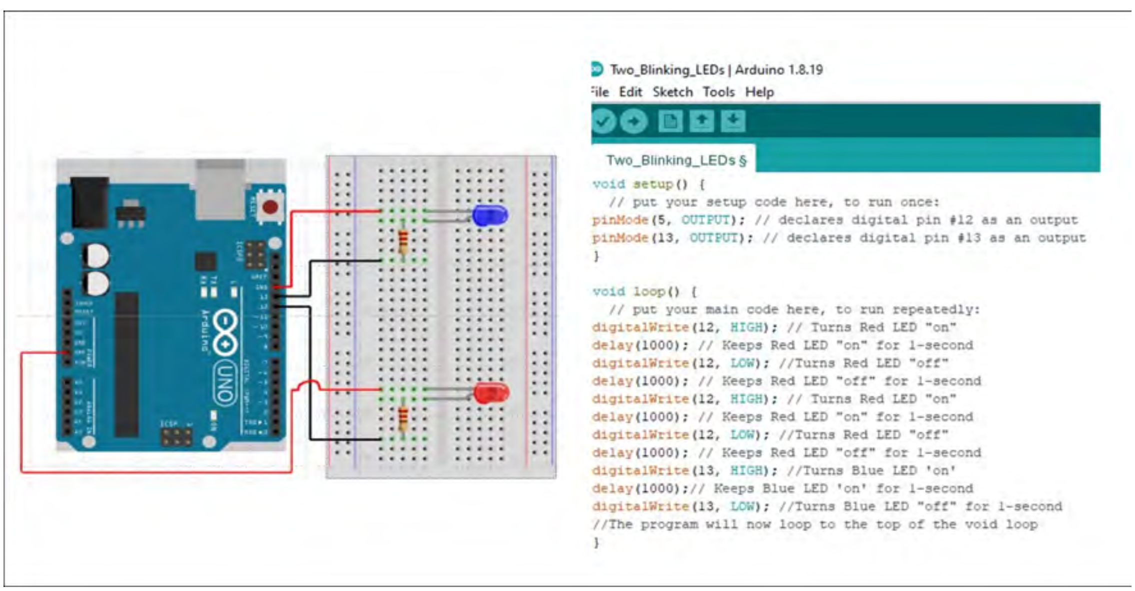

**Laboratory Activity.** On the second day (Wednesday) of the instructional treatment students met in a college computer laboratory to complete the same circuit breadboarding and Arduino programming activity used in the original study (Johnson et al., 2022). The activity required students to work alone to construct two LED (one blue LED and one red LED) circuits on the same breadboard and program the Arduino UNO to cause the LEDs to blink on and off in a specific order at a specified interval. Students were provided with a written activity sheet; a one-page student reference showing a pictorial drawing of a single resistor and LED circuit and the generic forms of the three

Arduino program commands required to program the circuit; an Arduino UNO, breadboard, and all necessary supplies to construct the circuits; and a computer with the Arduino IDE loaded. Students had 45 minutes to complete the laboratory activity. Prior to allowing students to begin, the instructor reviewed the laboratory activity and expressed confidence that the students would be able to successfully complete the activity (social persuasion experience). As students worked, the instructor made positive and encouraging comments (social persuasion experience); as students successfully completed the laboratory activity (mastery experience), the instructor held up the operating project and announced successful completion (vicarious experience). Once students either successfully completed the laboratory activity or time expired, students submitted their breadboarded circuits and copied their Arduino sketches into an online form and submitted them for grading.

**Debriefing.** On the third day (Friday), students were debriefed on the laboratory activity. A PowerPoint slide with a pictorial drawing of a correctly breadboarded laboratory circuit and a correctly written Arduino sketch was displayed and discussed (Figure 3). The instructor displayed and operated four correctly breadboarded and programmed student projects (mastery and vicarious experiences) and made positive and encouraging comments about student performance on the laboratory activity (social persuasion experience). The debriefing ended with a 5-minute mini lecture on applications of microcontrollers and embedded computing in agriculture.

**Figure 3**

*Slide Showing Example Breadboarded Circuit (left) and Arduino Sketch (right) for Laboratory Activity*



## Purpose and Hypothesis

The purpose of this study was to replicate and extend previous research (Johnson et al., 2022) which found that an instructional treatment based on Bandura's (1986) self-efficacy theory increased novice Arduino users' interest, self-efficacy, and knowledge. The following directional null hypothesis was formulated for testing at an experiment-wise error rate of .05:

> $H_0$: An instructional treatment (lesson and activity) will not significantly ($p \leq .05$) increase novice users' (a) interest in Arduino, (b) breadboarding self-efficacy, (c) Arduino programming self-efficacy or (d) Arduino knowledge.

This study also sought to describe students' performance on the laboratory activity for (a) circuit breadboarding, (b) Arduino programming, and (c) compatibility between the breadboarded circuit and the Arduino program and determine students' qualitative reactions to the instructional treatment.

## Methods

The population for this study consisted of novice Arduino users enrolled in introductory agricultural systems technology courses in US universities. The accessible sample consisted of students ($n$ = 52) enrolled in one introductory agricultural systems technology course at University A from the original study (Johnson et al., 2022) during the fall 2022 semester. Following IRB approval, 44 students consented to participate in the study and 35 students completed all research activities. Because the focus of this study was on novice Arduino users, three students who reported previous experience with Arduinos were eliminated from the study, leaving 32 students in the final data set.

**Research Design and Data Analysis.** Because the researchers deemed it unethical to withhold the instructional treatment from one group of students as a control, this study used a pre-experimental one-group pretest-posttest design (Campbell & Stanley, 1963). According to Christensen (1985), this design is useful "in situations in which it is impossible to obtain an equated comparison group" (p. 160). Flannelly et al. (2018) indicated the one-group pretest-posttest design was "probably the most common design used in [medical] program evaluation studies (p. 117), while Seifert et al. (2010) found this design was used in "about 25 percent of the published college impact articles in four major higher education journals" (p. 12).

Campbell and Stanley (1963) list history, maturation, and testing as primary threats to the internal validity of the one-group pretest-posttest research design. Because of the short duration (5 days) of the study, history and maturation should not have posed significant threats. Campbell and Stanley define the threat of testing as "the effects of taking a test [pretest] upon the scores of a second test [posttest]" (p. 5). Although testing cannot be completely ruled out as a potential threat in the current study, using data from the original study (Johnson et al., 2022) where only one group completed the pretest, the researchers determined there was no significant difference [$t(26) = -0.12$, $p = .90$] in

Arduino knowledge posttest scores between students who completed the knowledge pretest (*M* = 73.3%, *SD* = 18.6%) and students who did not complete the knowledge pretest (*M* = 74.2%, *SD* = 22.2%). This result also provides evidence against the interaction of testing and treatment as a threat to the external validity of the study.

A series of four paired *t*-tests were conducted to test parts a – d of the null hypothesis. To maintain an experiment-wise error rate of .05, the Bonferroni correction was applied, and each individual paired *t*-test was tested at an alpha level of .0125 (Field & Miles, 2012). Descriptive statistics were used to describe student performance on the laboratory activity and open coding (Williams & Moser, 2019) was used to analyze student comments.

**Instrumentation.** The pretest and posttest versions of two instruments used by Johnson et al. (2022) were used in this study. The first instrument contained sections designed to measure students' Arduino interest, circuit breadboarding self-efficacy, Arduino programming self-efficacy, and student demographic characteristics. The interest scale, adapted from Gable and Roberts (1983), contained 13 items measured on a 1 (strongly disagree) to 5 (strongly agree) Likert-type scale. The breadboarding self-efficacy scale contained eight items, developed by Johnson et al. (2022), measured on a 1 (very unconfident) to 5 (very confident) Likert-type scale. The programming self-efficacy scale, adapted from Kittur (2020), contained 13 items measured on a 1 (very unconfident) to 5 (very confident) Likert-type scale. The final section on the pretest elicited demographic information about respondents' academic classification, gender identity, previous programming experience, and whether students had previous experience with Arduinos. The pretest and posttest versions of this instrument were identical except that, on the posttest, the demographic section was replaced with an open-response item inviting students to share written comments about Arduinos and their experiences during the instructional treatment.

The second instrument consisted of two versions of an 11-item multiple-choice test, with four response options per item, used to measure student knowledge before and after the instructional treatment. All items were the same on both tests with the response options re-ordered on the posttest. Both test versions contained a 12$^{th}$ item asking students to rate their level of confidence (1 = not at all confident, 2 = fairly confident, or 3 = extremely confident) their answers were correct.

All instruments and scales used in the original study (Johnson et al., 2022) were examined by a panel of three experts in engineering education who were informed about the objectives of the study, the research procedures, and the characteristics of the research participants. The panel judged all instruments and scales to possess face and content validity. As shown in Table 1, the Arduino interest, breadboarding self-efficacy, and programming self-efficacy scales had high coefficient alpha reliabilities. The KR-20 reliability estimate for the Arduino knowledge posttest was low but higher than the typical mean of .50 for teacher-made tests (Frisbie, 1988). The low reliability of the Arduino knowledge pretest was consistent with guessing by novice students with little knowledge in the domain being tested (Paek, 2015). This was confirmed by the mean pretest score of 27.3% correct which was not significantly different ($z$ = 0.30, $p$ = .76) from the theoretical score of 25.0% by random guessing, and further substantiated by responses to the 12th item on the knowledge pre-test where 81.5% of students indicated they were 'not at all sure' their test responses were correct.

**Table 1**

*Pretest and Posttest Reliabilities for Scales used in the Study*

| Instrument or Scale | Pretest | Posttest |
|---|---|---|
| Interest in Arduino | .87 [a] | .89 [a] |
| Breadboarding self-efficacy | .98 [a] | .91 [a] |
| Programming self-efficacy | .93 [a] | .95 [a] |
| Arduino knowledge | .14 [b] | .62 [b] |

[a] Coefficient alpha reliability estimates. [b] KR-20 reliability estimates.

In addition to the pretest and posttest instruments, the course instructor used the rubric developed for the original study (Johnson et al., 2022) to score the student artifacts (breadboarded circuits and Arduino programs) created during the laboratory activity. The rubric consisted of 10 items for scoring circuit breadboarding, 14 items for scoring the Arduino program, and 2 items to score compatibility between the breadboarded circuit and the program. Each item was scored as being correct (1 point) or incorrect (0 point).

**Study Procedures**. This study was conducted over three class meetings during the 12th week of classes in the fall 2022 academic semester. At the beginning of class on the first day (Monday) students were presented with a brief (2 – 3 minute) illustrated lecture introducing microcontrollers and embedded computing systems in agricultural machinery. The instructor held up an Arduino UNO microcontroller and informed the students they were going to spend the week learning to breadboard electronic circuits and program the Arduino UNO. After this brief introduction, students completed pretest versions (paper and pencil) of the interest and self-efficacy and Arduino knowledge instruments. Next, packages containing an Arduino UNO, pin connector wires, one 240-ohm resistor, one LED, and a paper mock-up of the Arduino programming environment were distributed to every pair of students and the illustrated lecture with hands-on practice tasks was presented.

On the second day (Wednesday) students reported to a college computer lab in two approximately equally sized groups and completed the hands-on laboratory activity. After introductory comments, students had 45-minutes to complete the activity. Students were seated at every other computer station and worked individually. The only assistance provided by the instructor was to help students identify, if necessary, the computer port to which the Arduino was connected so they could download their programs.

On the third day (Friday) students were debriefed on the laboratory activity. Following debriefing, students completed posttest versions (paper and pencil) of the interest and self-efficacy and Arduino knowledge instruments.

## Results

Although the introductory agricultural systems technology course used in this study was a freshman-level course, a majority of the 32 novice Arduino users were either juniors (41.9%) or seniors (16.1%); first-year students (12.9%) and sophomores (29.0%) comprising a minority of students. Almost two-thirds of these students identified as male (65.6%) and over three-fourths (77.4%) reported no previous experience with any type of computer programming.

**Null Hypothesis (Parts a – d).** Student interest in learning about Arduino was measured on a 1 (strongly disagree) to 5 (strongly agree) summated Likert-type scale, administered before and after the instructional treatment. As shown in Table 2, students had an above average level of agreement ($M$ = 3.52) they were interested in learning about Arduino prior to instruction; the level of agreement increased ($M$ = 4.11) after instruction. The results of a paired $t$-test indicated the increase in student interest was statistically significant ($p < .001$) and the Cohen's $d$ of 1.12 indicated a large effect (Cohen, 1988) for the instructional treatment on student interest. Based on these results, subpart a of the null hypothesis was rejected.

**Table 2**

*Student Interest in Learning about Arduino Before and After Class and Lab Instruction*

| Measurement | *n* | *M* | *SD* | *t* | *p* | Cohen's *d* |
|---|---|---|---|---|---|---|
| Before Instruction | 32 | 3.52 | 0.48 | | | |
| | | | | 6.35 | <.001 | 1.12 |
| After Instruction | 32 | 4.11 | 0.54 | | | |

*Note*. Interest was measured on a 13-item summated scale where 1 = Strongly Disagree and 5 = Strongly Agree.

Student breadboarding self-efficacy was measured on a 1 (very unconfident) to 5 (very confident) summated Likert-type scale. As shown in Table 3, the mean student score of 1.89 indicated students had only slight confidence prior to instruction; after instruction, the mean student score of 4.43 indicated students were very confident in their circuit breadboarding abilities. The results of a paired $t$-test indicated the increase in breadboarding self-efficacy was statistically significant ($p < .001$) and the Cohen's $d$ of 2.22 indicated a large effect (Cohen, 1988) for the instructional treatment on breadboarding self-efficacy. Based on these results, subpart b of the null hypothesis was rejected.

**Table 3**

*Student Circuit Breadboarding Self-Efficacy Before and After Class and Lab Instruction*

| Measurement | *n* | *M* | *SD* | *t* | *p* | Cohen's *d* |
|---|---|---|---|---|---|---|
| Before Instruction | 32 | 1.89 | 1.10 | 12.53 | <.001 | 2.22 |
| After Instruction | 32 | 4.43 | 0.60 | | | |

*Note.* Breadboarding self-efficacy was measured on an 8-item summated scale where 1 = Very Unconfident and 5 = Very Confident.

Student Arduino programming self-efficacy was also measured on a 1 (very unconfident) to 5 (very confident) summated Likert-type scale. As shown in Table 4, the mean student score of 1.92 indicated only slight confidence prior to instruction; after instruction, the mean student score of 3.95 indicated students were moderately confident in their Arduino programming abilities. The results of a paired *t*-test indicated the increase in programming self-efficacy was statistically significant ($p < .001$) and the Cohen's *d* of 1.88 indicated a large effect (Cohen, 1988) for the instructional treatment on programming self-efficacy. Based on these results, subpart c of the null hypothesis was rejected.

**Table 4**

*Student Programming Self-Efficacy Before and After Class and Lab Instruction*

| Measurement | *n* | *M* | *SD* | *t* | *p* | Cohen's *d* |
|---|---|---|---|---|---|---|
| Before Instruction | 32 | 1.92 | 0.82 | 10.65 | <.001 | 1.88 |
| After Instruction | 32 | 3.95 | 0.69 | | | |

*Note.* Programming self-efficacy was measured on a 13-item summated scale where 1 = Very Unconfident and 5 = Very Confident.

On the knowledge posttest, 96.9% of students were either 'fairly' (71.9%) or 'extremely' (25.0%) confident their responses were correct. The mean student score on the Arduino knowledge pre-test was 27.3% and the mean posttest score was 80.7%. This increase was significant ($p < .001$) (Table 5). The Cohen's *d* of 2.79 indicated a large effect (Cohen, 1988) for the instructional treatment on Arduino knowledge. Based on these results subpart d of the null hypothesis was rejected.

**Table 5**

*Student Knowledge Before and After Class and Lab Instruction*

| Measurement | *n* | *M* | *SD* | *t* | *p* | Cohen's *d* |
|---|---|---|---|---|---|---|
| Before Instruction | 32 | 27.3% | 13.5% | 15.78 | <.001 | 2.79 |
| After Instruction | 32 | 80.7% | 15.6% | | | |

*Note.* Student knowledge was measured as the percentage correct on an 11-item multiple choice test with four response options.

All subparts (a – d) of the null hypothesis were rejected. Thus, the researchers concluded the instructional treatment based on self-efficacy theory (Bandura, 1986) was successful in significantly ($p < .001$) increasing novice users' (a) interest in Arduino, (b) breadboarding self-efficacy, (c) Arduino programming self-efficacy, and (d) Arduino knowledge. The increase in each area represented a large effect (Cohen, 1988) for the instructional treatment.

**Performance on the Breadboarding and Programming Activity.** The hands-on laboratory activity was evaluated using a scoring rubric with each item scored as either correct (1 point) or incorrect (0 point). The mean scores were 9.88 ($SD$ = 0.55) on the 10-item breadboarding section of the rubric, 13.50 ($SD$ = 2.48) on the 14-item programming section of the rubric, and 1.97 ($SD$ = 0.18) on the 2-item breadboarding and program compatibility section of the rubric. Twenty-eight of 32 (87.5%) students successfully completed the hands-on Arduino laboratory activity and made perfect (100.0%) scores on the breadboarding, programming, and compatibility sections of the evaluation rubric. The four students who did not successfully complete the laboratory activity made minor programming syntax errors (two students), compatibility errors in initializing the wrong digital pin (two students), and breadboarding errors by reverse-biasing the LEDs (one student).

The level of student performance on the laboratory activity was consistent with the findings of significant increases in student interest in Arduinos, programming self-efficacy, breadboarding self-efficacy, and Arduino knowledge reported by Johnson et al. (2022). Of particular interest, the level of student performance on the laboratory task was consistent with the increased level of Arduino knowledge as measured by the lower-reliability tests of cognitive knowledge.

**Student Comments.** In addition to quantitative data on interest, self-efficacy, knowledge, and task performance, students were invited to share any written comments they had related to learning about Arduino UNO microcontrollers, breadboarding electronic circuits, or programming the Arduino UNO. Twenty-six (81.2%) of the novice users provided one or more written comments on the after-instruction survey with all (100.0%) of these comments categorized as positive.

Fourteen (53.8%) students commented that they 'liked,' 'enjoyed,' or 'loved' learning about Arduinos. Example comments included:

- I liked learning about the Arduino UNO. At first, I did not understand the importance but now its cool that I know they [microcontrollers] are all around us. And I really liked actually getting to do it in the lab.
- I really enjoyed learning how to program the Arduino UNO. I felt very proud of myself after I had completed the project successfully.
- I loved learning about [A]rduino. It makes me want to invest in buying one and take more classes like this.

Seven (26.9%) students commented on the instructional treatment. Example comments included:

- I thought it was well prepared and laid out.
- This was very straightforward and easy for me to follow. Personally, I would have liked more of a challenge but that may not be possible for the others.
- No further comments: clear instruction[s] and simplified methods worked well.

Five (19.2%) students commented on the usefulness of learning about Arduinos and microcontrollers. Example comments included:

- One of the more useful things I have learned in college.
- Overall, this was a great experience, and I learned a lot. I feel like this could definitely come in handy someday for me when I'm around machinery.
- Arduino is easy to learn, and I believe I can use this information and Arduino in the future.

Finally, four (14.3%) students commented they would have liked to spend more time more learning about Arduino. Example comments included:

- [I] liked learning about it a lot – wish we had spent more time on it.
- I think if it [instruction] could be one day longer that would be helpful.

## Conclusions and Recommendations

This study replicated research by Johnson et al. (2022) to determine if an instructional treatment, based on self-efficacy theory (Bandura, 1986), would significantly ($p \leq .05$) increase students' interest in Arduino, circuit breadboarding self-efficacy, Arduino programming self-efficacy, and knowledge about Arduino. The study was conducted with a different sample drawn from the same population at University A used in the original study.

The results were consistent in that the modified instructional treatment produced the same results as when used at University B in the original study (Johnson et al., 2022). Namely, the instructional treatment had a significant ($p < .001$) and large (Cohen, 1988) effect and resulted in increased student interest in Arduino, circuit breadboarding self-efficacy, Arduino programming self-efficacy, and knowledge about Arduino. In addition, student performance on the laboratory task was excellent, with high scores on the breadboarding (98.8%), programming (90.0%), and compatibility (98.5%) sections of the rubric. Additionally, 28 of 32 (87.5%) students scored 100.0% on the rubric and produced laboratory projects that functioned as intended. This represents a substantial improvement over the 52.9% success rate reported by Sadler et al. (2017) on a less complex Arduino activity.

In addition to the quantitative results, open coding (Williams & Moser, 2019) of students' written comments on the posttest survey indicated that students responded positively to learning about Arduino and the instructional treatment. All student comments were classified as positive, with over one-half (53.8%) of the 26 students providing written comments indicating they 'liked,' 'loved,' or 'enjoyed' learning about Arduinos. Substantial percentages of students also commented that the instructional treatment was clear (26.9%), learning about Arduino would be useful (19.2%), or that they would like to spend more time learning about Arduinos (14.3%). Thus, the qualitative and quantitative results were consistent in pointing to the effectiveness of the instructional treatment.

This study confirms the results of Johnson et al. (2022). An instructional treatment based on Bandura's (1986) self-efficacy theory increased Arduino interest, self-efficacy, and knowledge. Breaking larger tasks into smaller, properly sequenced subtasks and allowing students to experience success in each subtask provided multiple opportunities for positive mastery, vicarious, and social persuasion experiences, increasing student interest, self-efficacy, and knowledge. In addition, these sequential subtasks, along with instructor enthusiasm and expressed confidence in student performance, promoted the positive physiological and emotional state associated with increased student self-efficacy.

This study demonstrated that novice agriculture students can successfully learn about Arduino UNO microcontrollers, circuit breadboarding, and Arduino programming, and that instruction based on Bandura's (1986) self-efficacy theory can increase student interest and self-efficacy related to this subject. In teaching microcontrollers and programming to novices, instructors should encourage students, express confidence in student abilities, teach enthuastically, break larger tasks into carefully sequenced subtasks, and provide multiple opportunities for students to experience mastery, vicarious, and social persuasion experiences.

Future research should extend these findings by seeking to identify instructional practices that build upon and sustain student interest and self-efficacy while gradually reducing students' reliance on instructor-initiated vicarious and social persuasion experiences. Relatedly, longitudinal research is needed to determine if the increased Arduino interest, self-efficacy, and knowledge resulting from self-efficacy-based instruction leads to subsequent enrollment in courses requiring more advanced Arduino use, or in increased personal Arduino use. Longitudinal research is also needed to determine the extent to which Arduino self-efficacy, knowledge, and (especially) interest sustains over an extended period.

Finally, given the consistent positive student outcomes from the original (Johnson et al., 2022) and present replication studies, educators should consider Bandura's (1986) self-efficacy theory when teaching technical or otherwise difficult content to novices. Based on the positive relationships between interest, self-efficacy, and student performance (Johnson et al., 2022; Lane et al., 2002; Smith et al., 2006; Ryan & Deci, 2000), attention to self-efficacy theory in the design and delivery of instruction should enhance both cognitive and affective student outcomes.

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