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Enhancing student motivation through a hands-on Raspberry Pi activity in an introductory IST course

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Abstract

This study explores the impact of a hands-on, project-based Raspberry Pi activity on undergraduate student motivation in an introductory Information Sciences and Technology (IST) course. Drawing on the principles of Course-based Undergraduate Research Experiences (CURE) and project-based learning (PBL), the intervention required students to build and program a simple electronic circuit using Raspberry Pi 5 kits, integrating hardware and software concepts through collaborative problem-solving. Using a cross-sectional survey based on the Intrinsic Motivation Inventory (IMI), the study measured self-reported levels of interest/enjoyment, perceived competence, pressure, and choice among 15 participants, with a focus on comparing first-generation and non-first-generation college students. Results indicated that all students reported high interest and enjoyment, with first-generation students demonstrating notably higher perceived autonomy (choice) and positive engagement than their non-first-generation peers. No significant differences were observed in perceived competence or pressure between groups. The findings suggest that hands-on, student-led activities using affordable technology like Raspberry Pi can foster motivation and engagement, particularly among first-generation students, and potentially minimize anxiety associated with technical tasks. Limitations include the small sample, single activity, and single-institution context. Future research should further explore the role of social interactions in such experiential learning environments and examine the broader applicability of these pedagogical approaches across diverse educational settings and larger sample populations.

Keywords: Raspberry Pi, problem-based learning, first-generation college students, intrinsic motivation; Python programming

Introduction

Raspberry Pi devices, which are small, relatively inexpensive, single-board computers, were originally developed in 2008 by Cambridge University professors for use in classrooms. The creators of the devices were motivated by widespread, declining enrollments in computer science and information systems degree programs; By making the devices widely available, their intention was not just to increase existing pipelines into the profession(s), but also to widen those pipelines to reach out to students who may not previously have had access to computing devices (Alan-Ramdial & Campbell, 2014). The extent to which these mini computers have fulfilled this promise, however, remains an open question. While scholars and practitioners alike have touted these the Pis as a low-cost way to teach hands-on programming **(**Major et al., 2021;

Rousouliotis et al., 2024), more empirical data is needed to examine the linkages between access to computing devices, student learning, and student persistence, especially for historically underserved populations. To contribute to the emerging body of evidence-based practice related to the integration of Rasberry Pis, the present study seeks to assess the degree to which these hands-on, problem-based learning activities foster higher levels of engagement and intrinsic motivation to learn, with a particular focus on first-generation college students.

Background and Literature Review

Problem-based learning (PBL) has long been identified as a signature pedagogy in computer science and information systems education (Christie, 2023; Kay et al., 2000; Pucher & Lehner, 2011; Raj et al., 2021). A popular variant of PBL, project-based learning, typically involves a more extended engagement with a particular problem or challenge, that often results in a shared artifact, such as prototype or poster. A more recent variant, Course-based Undergraduate Research Experiences (CUREs), occurs when a traditional lecture-based undergraduate course is transformed (whether in whole or in part) by students engaging directly in research or inquiry activities, such as conducting experiments, engaging in field work, or testing new solutions (Bell et al., 2025; Buchanan & Fisher, 2022; Walker et. al., 2023). The latter, while popular in the lab sciences, has only just started to attract attention in computer science and information systems education (Bekkering, 2025; Buffardi et al., 2024). All three variants share similar pedagogical roots, in which students work in collaborative teams to solve problems on their own, with varying degrees of structure and/or guidance from the instructor (De Graaf & Kolmos, 2007).

As a catalyst for problem-based learning, the integration of low-cost Raspberry Pi devices in educational settings has gained significant attention for their potential to enhance transferable skills, creative problem solving, and persistence in STEM careers (Major et al 2021; Csóka & Czakóová, 2021).. Mathe et al., (2024), for example, highlight the diverse uses of Raspberry Pi in scientific research and its practical implementations for (current and future) researchers, educators, and developers. Adhikary et al. (2024) identify a range of Raspberry Pi-based projects across various academic disciplines and professional fields. In information systems specifically, Cai et al. (2023) indicate that the Raspberry Pi activity contributed to higher levels of student engagement and a growing interest in cybersecurity by high school students (Cai et al., 2023; Balon & Simić, 2019; Currás-Francos & Rodríguez-Rodríguez, 2023). Similar findings were also reported by Al Dahoud et. al., (2021) for college students. A more recent quantitative study by Al Dahoud et al. (2024) provided benchmark tests on various Raspberry Pi models and concluded that the platform is not only affordable but also effective for building computing and problem-solving skills. Taken collectively, these studies affirm the educational value of integrating the Raspberry Pi into problem-based learning, offering both theoretical insights and real-world application data that justify its inclusion in introductory IT and programming courses.

Research on problem-based learning with Rasberry Pi devices, as described above, is an emerging field, with many open lines of inquiry regarding how, why, and for whom such activities impact student learning. And the stakes are higher than just passing a class for these students and for society at large. Active and inquiry-forward pedagogical strategies such as problem-based learning, project-based learning and course-based undergraduate research have been identified as high-impact practices, meaning that they have a demonstrable impact on student success, in ways that may be more equitable than their non-course-based alternatives (Hensel, 2023; Ruth et al., 2021; Smith et al., 2023). The effect of such strategies on first-generation college students, defined here as students whose parents do not hold 4-year college degrees, however, has received mixed results in research studies (Martin et al., 2021). Indeed, a recent systematic review of the literature concluded that motivation broadly, and self-efficacy specifically, "is a construct that

may need further examination in relation to first-generation college students" (Ives & Castillo-Mantoya, 2020, p. 152). This matter is critical, as 54% of all current U.S. college students identify as first-generation (firstgenforward.org, 2020).

Researchers have identified several factors that may contribute to diminished motivation on the part of first-generation students to engage in problem-based learning. A 2014 study by Bangera and Brownell, for example, indicates that first-generation students and their families, for are often unaware of the importance of hands-on projects and research experiences in relation to both career-readiness and admission to graduate level programs (Bangera & Brownell, 2014; Tierney et al., 2024). Other scholars have emphasized that the integration of these pedagogical approaches can been perceived as contributing to persistent issues with cognitive overload (Stebleton & Soria, 2012; Ives & Castillo-Mantoya, 2020), challenging first-generation students to engage in unfamiliar activities and uncomfortable interactions with peers and instructors.

Alternatively, other studies have demonstrated that the motivational benefits of hands-on activities may be likely to accrue disproportionally to first-generation STEM students, including those in computer science and related fields. Studies have shown that these kinds of hands-on learning experiences have contributed positively to their intrinsic motivation to learn; enhancing attributes such as interest, agency, and belonging (Carver et al., 2017; Hang et al., 2020; Svihla et al., 2017; Wilson, 2023). Indeed, the counter argument to the cognitive overload hypothesis (in previous paragraph) is that such activities do not require first-generation students to have already mastered the meta-cognitive skills needed to succeed in traditional modes of instruction embedded in unfamiliar university settings.

To reconcile this apparent contradiction in the literature, the researchers sought to explore how problem-based learning activities using Rasberry Pis impacted both traditional and first-generation college students This cross-sectional, survey-based study focuses on the experiences of students (n=15) enrolled in a lower-division information systems course offered at a small, urban campus located in the eastern part of the U.S.. In the Carnegie classification system, the university is designated as an opportunity institution, meaning that it provides (close to) open access, particularly for students from low-income and historically underrepresented populations. At the same time, the campus is part of a much larger university system, which contributes to its graduates achieving comparatively higher post-graduate earnings, especially for high demand applied fields such as engineering and information systems. As such, the campus provides an auspicious environment for testing the aspirations of Rasberry Pi's creators to motivate students from a wide range of socio-economic backgrounds to engage in hands-on learning by programming with real, albeit very small, computers.

Methodology

This exploratory, cross-sectional, survey-based research study assesses the outcomes of a pedagogical intervention in the form of a project-based learning activity where students used Raspberry Pi 5 kits to explore how computers interact with physical components. The course used in this study was IST 140: Introduction to Application Development. According to the course syllabus, the learning objectives included: understanding the fundamentals of programming, developing problem-solving skills through algorithmic thinking, and creating simple applications using Python. The course emphasized hands-on experience and collaborative problem-solving, which made it an ideal environment to introduce the Raspberry Pi 5 as a learning tool for hardware-software integration and real-world application development. During the exercise, students worked with their own kit to build a simple circuit containing an LED light and a resistor, connecting these components to the Pi's GPIO (General Purpose Input/Output) pins. Students then wrote Python programs to control the circuit, creating code that made the LED blink on and off in different patterns. The activity focused on key concepts like setting up GPIO pins, writing loops to repeat

actions, and using delays to control timing. Four student researchers helped guide the class, walking around to check circuits, debugging wiring issues, and explaining programming steps. The goal of the exercise was to teach troubleshooting skills, as students learned to fix common problems like loose wires or incorrect pin assignments.

The study sought to identify correlations between (self-reported) participant motivation and the technology and the PBL intervention. Student motivation was measured via an electronic survey, consisting of 22-Likert scale items from the Intrinsic Motivation Inventory (IMI) scale and 5 demographic questions (semester standing, gender identity, age, race/ethnicity, first generation standing). First developed by psychologist Richard Ryan (1982), the IMI has been extensively used in education settings as a measure of the components of intrinsic motivation. The version used for this study (provided by the creators of the instrument) focuses on a specific task (i.e., the Raspberry Pi activity). The study incorporated four IMI subscales: interest/enjoyment (7 items), competence (5 items), pressure (5 items) and choice (5 items). The validity and reliability of the IMI has been tested in multiple contexts, with the most widely cited version used with undergraduate students reporting an overall Cronbach's alpha coefficient of .85 (good) (McAuley et al., 1989, p. 51).

The survey was administered in the Fall semester of 2024 after the institutional review board at Penn State University approved the study at the exempt level. A member of the research team who was not the instructor provided links to the survey, which the instructor posted in the LMS course-shell following the close of the activity. Students who completed either the research survey (or, for non-consenting students, an approved alternative, not included in the study) were provided with low-stakes extra credit. A total of 15 students consented to have their responses included in the study, for a participation rate of 68% (15 out of 18).

The researchers used descriptive and analytical statistics to analyze student responses to the survey. The researchers determined that the data set is not conducive to tests of correlation, e.g., Chi-square, as these tests have a high risk of skewing findings with response frequencies this small. Tests of significant difference (Wilcoxon and t-tests) are commonly used statistical tools in other studies that utilize the IMI instrument in educational settings. For this study, a Wilcoxon signed rank test was selected because such tests are intended for use with non-parametric (scaled) data and the survey responses were not paired, therefore not meeting the conditions for a t-test. Further, Wilcoxon tests are generally approved for use with small data sets with limited risks of data infidelity. All statistical tests were run using the Flextable package in R (open source). Two members (1 faculty member and 1 student researcher) of Penn State University's Center for Teaching and Learning, neither of whom were involved in course instruction, conducted the analysis and verified the findings.

Results/Findings

A total of 15 students participated in the study, the majority of whom identified as male (11 of 15, 73%), white (7 of 15, 43%), and second year (8 of 15, 53%), characteristics which are roughly reflective of the demographic composition of the degree program. Participants were close to evenly split in terms of first-generation status, with 7 identifying as first generation and 8 identifying as non-first generation, which enabled the researchers to run tests of statistical difference between the latter two demographic groups.

Overall, participating students, regardless of their first-generation status, reported the highest levels of agreement with survey items related to interest/enjoyment. Participants ranked each item along a five-point Likert scale, with 5 indicating the highest level of agreement with each statement (see Table 1). This means that the students overall had a positive response to their engagement with the activity.

Interest and enjoyment, as measured by this scale, should not, however, be equated with satisfaction. The IMI survey instrument is based on Deci & Ryan's theory of self-determination (2008), which links enjoyment to intrinsic motivation. The theory suggests that students with high levels of interest and enjoyment are more likely to engage in self-directed learning and less likely to rely on external incentives or penalties (such as grades) or need close instructor monitoring.

Table 1. Intrinsic Motivation Inventory (IMI) Interest/Enjoyment Subscale, Participant Responses

Scale Item	Mean	SD	Median	Min	Max
While I was working on the activity I was thinking about how much I enjoyed it.	4.27	0.70	4	3	5
I found the activity very interesting	4.60	0.63	5	3	5
Doing the activity was fun.	4.60	0.63	5	3	5
I enjoyed doing the task very much.	4.60	0.63	5	3	5
I thought the activity was very boring (R).	1.53	0.64	1	1	3
I would describe this activity as very enjoyable.	4.07	1.10	4	1	5
I thought the task was very interesting.	4.13	1.06	4	1	5

(Perceived) Competence

Overall, participating students reported the second highest levels of agreement (median of 4 or 5) with items related to perceived competence, with no statistically significant differences reported between students identifying as first-generation and non-first generation (see Table 2). This means that overall, most of the students believed that they could engage in the Rasberry Pi activity appropriately and effectively. It should be noted, however, that this perception was not universal. There was at least one student who ranked themselves at the lower end of the scale (response of strongly disagree (1) or disagree (2) for each item in the subscale. In Deci & Ryan's self-determination theory, competence is considered one of the three necessary components (competence, autonomy, and relatedness) that contribute to higher levels of intrinsic motivation. In this case of the Rasberry Pi activity, student autonomy was integrated as part of the design of the activity, and relatedness was encouraged through teamwork and peer mentoring. This means that students who believed themselves to be capable of engaging in the activity were more likely to be positively motivated to learn from their experiences.

Table 2. Intrinsic Motivation Inventory (IMI) Competence Subscale, Participant Responses

Scale Item	Mean	SD	Median	Min	Max
I think I am pretty good at this activity	4.1	0.92	4	2	5
I think I did pretty well at this activity, compared to other students.	4.13	1.13	4	1	5
After working at this activity for awhile, I felt pretty competent.	4.27	0.70	4	3	5
I am satisfied with my performance on this activity.	4.33	0.90	5	2	5
I felt pretty skilled at this activity.	4.13	1.13	4	1	5

Pressure

Overall, students reported relatively low levels of stress or anxiety when participating in the activity, regardless of their first-generation status (see Table 3). This finding contradicts several earlier studies which suggested that first-generation students are more likely than traditional students to experience problem-based learning as a source of stress (see literature review above). It should be noted that three items in this subscale are reverse scored (R), meaning a lower numerical score is indicative of lower levels of stress or anxiety.

In self-determination theory, when the conditions of positive motivation (autonomy, competency, and relatedness) are met, students can exercise resiliency when engaging in novel learning experiences. When those conditions are not met, however, students are more likely to react to novel learning experiences with stress, frustration, and/or anxiety. This suggests that most students in the course were able to meet the conditions for positive motivation, thereby enabling them to engage in the activity with only mild levels of negative affect.

Table 3. Intrinsic Motivation Inventory (IMI) Stress and Anxiety Subscale, Participant Responses

Scale Item	Mean	SD	Median	Min	Max
I did not feel nervous at all while doing this	3.60	1.35	4	1	5
I felt tense while doing this activity (R).	2.27	0.96	2	1	4
I felt relaxed while doing this activity.	3.67	0.98	4	2	5
I was anxious while working on this activity (R).	2.40	1.24	2	1	5
I felt pressured while doing this activity (R).	1.86	0.83	2	1	3

Choice

The subscale regarding choice was the only scale on which persistent, and in one case ("I didn't really have a choice about doing this activity"), highly statistically significant *(p*-value of .04), differences appeared between students who identified as first-generation and those who did not (see Table 4). In this case, students who identified as first-generation consistently indicated higher overall levels of perceived choice, or autonomy, when engaging in the activity, then their non-first-generation peers across all five constructs in the sub-scale. It should be emphasized that the sample size for these comparisons was small, which limits the strength of these statistical insights—the findings here should be treated as suggestive rather than definitive.

In Deci and Ryan's self-determination theory, choice, or autonomy, is one of the essential conditions for intrinsic motivation and self-directed learning. In this case, both groups (first generation and non-first generation) experienced the same conditions (a required classroom activity), but reported different levels of perceived choice or autonomy in how they engaged with solving the problem using the Rasberry Pis. In one sense, this finding affirms prior studies that first generation students may not be as accustomed to hands-on problem-based learning, thereby registering the degree of autonomy as more novel; but, at the same time, the shared findings suggest that the perception of choice enabled, rather than inhibited, the intrinsic motivation of first-generation of students to learn from their experiences.

Table 4: Intrinsic Motivation Inventory (IMI) Choice Subscale, First-Generation vs. Non-First Generation Students

Scale Item	t	df	T Test p-value	Wilcoxon p-value	W	Mean Group 1 (First Generation)	Mean Group 2 (Non-First Generation)
I felt like I was doing what I wanted to do while I was working on the activity.	0.03	46	0.97	0.96	484	3.92	3.92
I felt that it was my choice to do this activity.	0.61	43	0.54	0.43	549	3.71	3.51
I didn't really have a choice about doing this activity (R).	.00	45	0.05	0.04**	346	2.08	2.71
I felt like I had to do this activity (R).	1.90	49	0.06	0.11	379	2.42	2.98
I did this activity because I had no choice (R).	1.72	50	0.09	0.10*	375	2.00	2.51

* = Somewhat Significant | ** = Very Significant

Discussion of Findings

The research findings join those of prior studies which indicate that problem-based learning using Raspberry Pis has positive benefits for students. The present study suggests that such activities benefit students not only in enabling them to learn new transferable skills, but also in strengthening their intrinsic motivation to learn those skills. The creators of Raspberry Pi, however, had even greater aspirations for these little devices—the wanted them to provide opportunities for students from historically under-served populations to gain access to, and interest in, careers in computer science and information systems.

Prior research presented conflicting findings regarding the engagement of first-generation students in problem-based learning, with some studies suggesting that such activities were de-motivating, and others suggesting that they provided positive benefits, not just in learning, but also in non-cognitive, affective attributes such as confidence and belonging. The findings from the present study provide evidence to support the latter hypothesis, with particular emphasis on intrinsic motivation and self-directed learning.

In Deci & Ryan's self-determination theory, a combined sense of competency, autonomy, and relatedness are needed to contribute to intrinsic motivation and positive well-being (2008). In this study, first-generation students reported similarly high levels of interest/enjoyment and competence as their non-first-generation peers. They also reported similarly low levels of stress or pressure. Prior research might suggest that there would be greater differentiation between the groups, with first generations students more likely to struggle with this type of exercise.

We conjecture that the presence of peer mentors may have contributed to a supportive classroom environment. Additionally, first-generation students reported consistently higher levels of choice when compared to their non-first-generation peers, suggesting that they felt a stronger sense of agency when engaged in real-world, problem-based learning activities. When coupled with high levels of interest/enjoyment and competence, this has implications for persistence, not only within the degree

program itself, but also into advanced study and/or information systems professions.

Limitations

The study took place at a small campus, which meant that the sample size for the study was similarly small, which limits the strength of the statistical analysis, especially for the tests of significant difference. The scope of the study was also limited to single-class exercise. While the IMI instrument was developed for use with single activities, it can also be used as a repeated measure for multiple activities integrated over the course of a semester, a design which could strengthen the reliability of future findings. Because the study took place at a small campus, only one section of the course is offered in a given semester, thereby making comparisons between a control and experimental group not a feasible option.

Further complicating the absence of a control group is the fact that, while the students participating in this study indicated that they had not worked with Rasberry Pis previously, that will no longer be the case for future studies with the same student cohort. Lastly, the study took place on a single campus, which limits the generalizability of the results to other contexts. More research will need to be conducted, across different institutions and with more students, to assess the replicability of the findings.

Conclusions and Future Research

Additional research is needed to determine the reliability and generalizability of the findings from this study, but there are two implications that appear promising. First, the researchers hypothesize that the role of the social environment in the classroom may have been a contributing factor to the levelling of experiences between first-generation and non-first-generation students. This was an incidental, emergent finding that could be tested in future studies, with particular attention to the role of class size in fostering such environments.

It seems challenging, but not impossible, that a similarly supportive environment could be fostered in a large-enrollment class. Indeed, scholars have suggested that in environments with resource restrictions, such as reduced access to computer labs or equipment, these limitations could be addressed through the provision of low-cost equipment, i.e., Raspberry Pis) coupled with rich, informal exchanges between staff, students, and faculty, a practice deemed relationship-resourced resiliency (RRR) (Ebersöhn, 2013). The potential interactions between social and cognitive learning, such as RRR, have not (yet) been extensively studied in the context of information systems education.

If replicated, the findings of this study suggest evidence-based strategies for enhancing the motivation of first-generation college students to pursue degrees in high-demand, often high-earning, fields such as computer science and information systems. It could prove insightful to further assess the integration of these strategies in even more resource-limited contexts, especially those with relatively high percentages of first-generation college students, such as two-year and community colleges. With nearly all U.S. higher education institutions currently facing declining enrollments and increasingly dire financial futures, however, the combination of low-cost resources (i.e., the Raspberry Pis), relationship-rich pedagogy, and problem-based learning has the potential to be both transformative and sustainable.

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