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RESEARCH ARTICLE

Learning Astronomy by Teaching: A Service-Learning Section of Introductory Astronomy

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Abstract

This work presents the development and assessment of a university service-learning course in introductory astronomy for nonscience majors designed for community engagement and experiential learning. The service-learning component of the required students to design, plan, execute and evaluate activities for fifth grade students in an after-school program. Students in the service-learning section of the course (N=14) report positive gains in astronomy content learning, 7.3% higher on a standard assessment post-test than for a non-service-learning section of the same course (N_{pre}=46, N_{post}=40). From a self-assessment tool (N_{pre}=6, N_{post}=9), service-learning students reported 5-85% gains in all but one measure of attitudes towards science and confidence in their ability to apply and integrate astronomy knowledge and skills. Qualitative feedback from service-learning students indicate that experience positively affected their orientation towards teaching as a profession. Applying the service-learning model more broadly is logistically challenging, but has potential to be fruitful for learning and subject appreciation in other STEM domains.

Keywords: service learning; general education; introductory astronomy

1 Background

The inclusion of science in a university general education curriculum recognizes the need for science literacy in a democratic society, to support public health and economic growth, and to enable critical thinking that fosters informed decision-making. Broad-based science instruction for all is an important factor for societal literacy, appreciation, and support of science (Feinstein et al., 2013).

The Next Generation Science Standards, adopted by 20 states and the District of Columbia, emphasize three components: disciplinary core ideas; cross-cutting concepts; and science and engineering practices and emphasize that science education in K-12 schools should reflect science as it is "...practiced and experienced in the real world." National Research Council (2013). These standards inform the movement towards active instructional methods, not only in K-12 settings, but also in college classrooms (Stanberry and Payne, 2018). Active and experiential learning methods have been shown to improve student learning (Prather et al., 2009; Freeman et al., 2014) and to reduce the achievement gap in STEM courses for students from underrepresented or low-income backgrounds (Theobald et al., 2020).

Service-learning is a form of experiential education in which students engage in structured activities designed to promote student learning while also meeting community needs. Reflection

and reciprocity are important aspects of service-learning (Jacoby, 1996; Mintz and Hesser, 1996).

In this work, I report on a project to develop and assess an undergraduate service-learning course in astronomy for nonscience majors. The course is based on an existing university general education science lab course. The content of the course- observational astronomy, telescopes, Earth as a planet, the Moon, Solar System, Sun, general properties of stars- lends itself well to activities that can be done with elementary- or middle-school-aged students in after-school programs. Students in the service learning section of the course use their content knowledge along with many existing teaching and outreach resources to plan the activities, tailoring them to the specific needs and interests of the partner organization.

Although it is not specifically inquiry-based instruction in the usual sense that students model scientific inquiry to learn course concepts, the service-learning framework involves highly active methods for students to integrate and apply knowledge and to reinforce their understanding of course concepts. The content learning goals of the course are consistent with university guidelines for the core curriculum. The service learning goals of this course are to improve student aptitude and confidence in science and attitudes toward science education on the part of nonscience majors and to attract more students to the teaching profession. The second goal is motivated by the fact that, despite reforms in science education, current needs for science teachers in the U.S. are significant. There is a critical shortage of STEM teachers, especially in high school physics, chemistry, and mathematics, but the number of certificates awarded for teaching STEM in secondary schools is decreasing (Felder, 2022).

2 Theory

This study is constructed using a framework articulated by Giles and Eyler (1994) and rooted in Experiential Learning Theory (Kolb, 1984) with foundations in Lewin's theory of action research (Lewin, 1946) in which a continuous feedback process is used to direct action, evaluate outcomes, and direct further action. In the context of this work, the action is teaching introductory-level science, specifically astronomy, to nonscience majors in a university setting, and the outcomes to be evaluated are thus student learning.

Embedded within the action research model is a theory of student learning through teaching others that employs Dewey's model of learning as a similar feedback process that results in intellectual development (Dewey, 1938). Student learning is itself a progressive cycle from concrete experience to observation and reflection to the formation of abstract concepts and generalizations to the testing of the implications of those concepts in new scenarios, yielding new concrete experiences. Progression, i.e. learning, arises from the "higher-order purposeful action" (Kolb, 1984) involved in applying knowledge gained from previous experience to new experience. Application of Experiential Learning Theory to service-learning recognizes the importance of (a) the placement of reflection between a concrete experience and the generalization and application of knowledge and (b) multiple opportunities to engage in the cycle McEwan (1996).

The theoretical framework for service-learning developed by Giles and Eyler (1994) by applying Dewey's educational philosophy produced new areas for further inquiry. This study intersects with three of the nine themes they outlined:

- Reflective activity- Does service-learning connect education and experience by enhancing learning outcomes?
- Concrete and abstract knowledge- Does service-learning develop both conceptual knowledge and the skills to apply it?
- Inquiry- Does the service-learning experience inspire students to learn more within the domain of astronomy and/or influence their attitudes about teaching as a profession?

Mintz and Hesser (1996) emphasize the importance of grounding a service-learning program in principles of collaboration, reciprocity and diversity. Additionally, Howard (2001) articulated ten principles for implementing service-learning in higher education that emphasize the importance of academic rigor, clear content and community learning objectives, and intentional instructional design and community placement. The service-learning model employed by the Towson University Office of Civic Engagement and Social Responsibility is based on these principles and has the following components:

1. Meaningful Connection to Discipline
2. Preparation
3. Partnership and Reciprocity
4. Reflection
5. Assessment and Evaluation

Below I describe how Experiential Learning Theory was applied in a service-learning course to design activities with connection to a discipline (here, astronomy) that provide concrete experiences (student-led activities), encourage reflection through written assignments, and allow students to apply their learning in the next round of student-led activities.

The Giles and Eyler (1994) themes guided the overarching goals of this action research, which are for students to develop a deeper understanding of the course material and its relevance to their lives and communities through service-learning and to determine if this approach fulfills student learning outcomes for science-based education in the university's core curriculum. In the future, the application of the service-learning model to other courses and disciplines may thus improve science instruction institution-wide. An additional potential benefit of this research is a contribution to the small body of knowledge about the effectiveness of service-learning as a strategy for increasing student self-efficacy in science and improving student aptitude and attitudes towards science and science education.

3 Methods

This course described here is similar to a service-learning course at Misericordia University in which the university students hosted astronomy observation sessions for fifth- and sixth-grade students from two nearby elementary schools. Orleski (2013) outlines the course structure and lessons learned but does not address specific learning measures for students in the course. Similarly, Zainon (2020) described a model for university students to engage with astronomy content through design and implementation of learning activities for younger students. Subsequent assessment showed positive attitudes on the part of the university students and enhancement of content understanding among the participating primary school students.

The goals of this research are articulated in two specific objectives:

1. To measure how student content learning gains in a service-learning section of an introductory astronomy course for non-

science majors, ASTR 161 The Sky and the Solar System[1], compare to those of students in regular sections of the same course.
2. To determine if the service-learning aspect of the course impacts students' attitudes, self-efficacy and pedagogical content knowledge in astronomy.

3.1 Community Partner

Wolfe Street Academy (WSA) is a Baltimore City Public School Community School Conversion Charter School serving students and their families in the Upper Fells Point neighborhood. The school provides high-quality academic programming and helps families develop resources to overcome barriers to success. We partnered with the director of out-of-school programming to visit the school's after-school program for fifth grade students.

We obtained written permission from the school principal and signed a Memorandum of Understanding with coordinator at the partnership site, shown in Section 10.1.

3.2 Structure of the Service-Learning Course

Astronomy courses are among the most popular general education or Core curriculum courses at Towson University (TU). We offer about ten sections of ASTR 161 The Sky and the Solar System and about 8 sections of ASTR 181 Stars, Galaxies and the Early Universe, each semester, and they usually fill to capacity. Both courses satisfy the TU Core 7 requirement for Biological and Physical Science with a lab. The courses are usually taught as a lecture that meets twice weekly comprising two lab sections that each meet for an additional two hours weekly for laboratory activities to reinforce course concepts.

I taught the service-learning section of ASTR 161 The Sky and the Solar System in the spring 2022 semester. It met separately from other sections of the course, in a lecture-lab format, to accommodate the integration of service activities into the schedule, along with the lectures and the labs. A flyer designed to recruit students to the service-learning section of the class is shown in Figure 1.

Before the beginning of the semester, I sent an email to all students enrolled in the section informing them how the course will differ from regular sections of ASTR 161, with an articulation of the specific requirements for service learning. Students enrolled in the service-learning section were required to sign an agreement (Section 10.2) demonstrating they understood and agreed to abide by the service-learning expectations and guidelines (Section 10.3), which were developed with input from the community partner. Signing the agreement was a requirement for the course but was separate from the consent form for this study because enrolled students were not required to participate in the research study.

A Zoom meeting between the TU students and the community partner (coordinator) was conducted at the beginning of the semester in which TU students heard some of the astronomy related questions generated by the WSA students, listed in Section 10.4.

Each service-learning visit consisted of three parts: Preparation, Execution, and Reflection. Students were divided into five groups.

1 ASTR 161 is a Towson University Core 7 and 8 course in the biological and physical sciences. Towson University's Core Curriculum Requirements are described in the TU Undergraduate Catalog: https://catalog.towson.edu/undergraduate/core-curriculum-requirements/

Figure 1. Flyer for the Service-Learning Section of ASTR 161 The Sky and the Solar System

Each group had different roles that rotated for each visit to the partner school:

- **Lead group:** designed and led the activity, which could be based on a modified version of a class laboratory activity, informed the Equip group of their material and equipment needs, assigned the Assist group their roles.
- **Equip group:** with help of the instructor, acquired the materials and equipment needed and transported them to the program site on the day of the activity, monitored throughout the activity, and cleaned up and transported materials back as necessary after the activity
- **Assist group:** directly took part in the activity in the roles assigned by the Lead group and assisted the Equip group as needed, especially with clean up.
- **Assess group:** attended the activity but did not participate. Instead, they observed to assess the activity and provided feedback using an instructor-provided rubric.

Due to the size of the class and the limited number of roles, one group was allowed to sit out a visit each time, so every student made four visits to the partner school with each of the four groups. The class also had two undergraduate learning assistants (ULAs), an astrophysics major and an astronomy minor. One ULA accompanied the class for each visit.

All students who participated each week wrote a reflection on the activity and their role in it using an instructor-provided rubric. Reflection questions centered on the activity logistics, pedagogy and astronomy content. Lead groups were expected to incorporate these reflections into their activities in subsequent visits. Reflection questions posed to each group are given in Section 10.5.

3.3 Activities

The activities designed by each Lead group were typically variations of activities or labs already completed by the students for the course content learning. The following activities were performed by the ASTR 161 students with the WSA students in the spring 2022 semester:

- **Solar System Mobile**: Students used paper to construct a mobile with the distance scale model of the separation of the planets in the solar system.
- **Moon phases model:** Small paper cut-outs of moon phase images were arranged in order. Students modeled lunar and

Number	Age	Gender	Major
1	20	F	Gerontology
2	20	F	Art+Design
3	24	M	Mass Communication
4	18	F	Computer Science
5	22	F	Information Technology
6	21	M	Economics
7	20	F	Secondary Education
8	19	F	Pre-Early Childhood Education
9	29	F	Mass Communication
10	18	F	English
11	26	F	Gerontology
12	22	M	Earth Space Science
13	21	M	Computer Science
14	22	M	Computer Science

Table 1. Study participants from 2022 spring ASTR 161 class

solar eclipses.

- **"Play doh" planets**: Modeling dough was used to create size scale models of the planets.
- **Crater making**: Small projectiles were used to make craters in trays of flour and cocoa to investigate crater size and ejecta.
- **Spectroscopy**: Discharge tubes and small gratings were used to match emission line colors and patters to elements displayed on a poster.

3.4 Structure of Research Study

Participants were recruited from among 21 students enrolled in the spring 2022 service-learning section of ASTR 161 The Sky and the Solar System. Students enrolled in the service-learning section of the course were not required to participate in the research study. To reduce the risk of coercion, another professor not affiliated with the class presented the study information and collected consent forms. Consent forms were kept in a sealed envelope in the principal investigator's office and locked in a file cabinet until the end of the semester and were not unsealed until study data were analyzed. All analysis occurred after submission of final course grades.

The study uses convenience sampling; therefore any student enrolled in the course was allowed to participate, regardless of age, sex, or ethnicity. Participants were not required to complete extra coursework or assignments beyond those required of all students in the course. All students were expected to complete required assignments regardless of their consent to participate in the research study.

4 Data Description

Fourteen study participants were recruited from among the 21 students enrolled in the spring 2022 Service Learning section of ASTR 161. Participant information is listed in random order in Table 1. The age and major listed were those applicable in January 2022, at the beginning of the spring 2022 semester.

To assess student learning, data were collected using the following instruments:

1. **Written course work**: Students engaged in the development of activities for youth in an afterschool program. Students completed written peer assessments and reflections on their roles in the activities. These reflections were part of all students' course grades.
2. **Instructor observations:** The instructor observed the students in a supervisory role, taking written field notes regarding students' teaching practice and application of course concepts. Notes were used to give instructor feedback to Lead, Assist and Equip groups.
3. **Partner feedback:** As a regular part of the service learning course, a portion of feedback for the Lead, Assist and Equip groups came from the community partner when it was available. (There were occasions when the partner was unable to observe the activities directly and provide feedback.)
4. **Course Assessment:** Assessment data were collected as part of the regular course assessment activities described in the ASTR 161 Assessment Plan submitted to the TU Office of Assessment. Learning gains are calculated from a pre-test given in the first week of the semester and the same instrument repeated as a post-test at the end of the semester. The instrument consists of twelve multiple choice questions covering the course content. The ASTR 161 course assessment instrument is included below in Section 10.6
5. **SALG Survey:** The Student Assessment of Learning Gains (SALG) is a validated, customizable online tool for students to report their own learning. The SALG survey is hosted by the Wisconsin Center for Educational Research at the University of Wisconsin-Madison. Study participants completed the survey at the beginning and end of the study period. The SALG survey questions are included below in Section 10.7
6. **Optional Course Feedback Survey:** This was administered anonymously to students at the end of the semester to solicit feedback on three specific questions.

All students enrolled in ASTR 161 The Sky and the Solar System were evaluated by instruments 1-4, regardless of their agreement to participate in the study as these activities are a regular part of the course. Student learning assessment data (1-3) was collected during or after four visits to the service learning site throughout the spring 2022 semester as part of normal coursework activities. Each student received feedback from classmates in the Assess group (2); from the instructor (3) and from the community partner (4) for the activities they led in the Lead Group and coordinated in the Equip and Assist Groups.

Student reflections and Instructor and Partner feedback were used for course grading. The analysis presented in this paper focuses on Course Assessment data, SALG survey results and the Course Feedback survey (4-6).

The course assessment pre/post-tests were delivered in class with the instructor present. The SALG and course feedback surveys were completed by participants outside class time. All results were analyzed after the final course grades for the 2022 spring semester were submitted.

5 Analyses

5.1 Course Assessment

The assessment instrument used for the 2022 spring service-learning section of ASTR 161 was the same as used for all other non-service-learning sections of the course. To compare the assessment outcomes for students in this spring 2022 service-learning section of ASTR 161 to a non-service learning section taught by the same instructor, course assessment results from a non-service

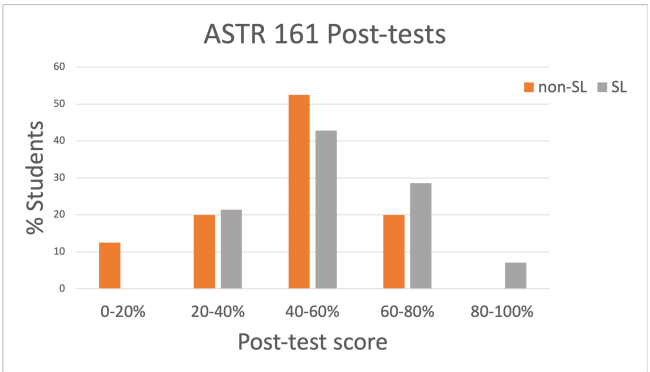

Figure 2. Comparison of assessment post-test scores for section of ASTR 161 The Sky and the Solar System with (N=14) and without (N_{pre}=46, N_{post}=40) a service-learning component

Learning Goal	Measure 1 Questions	Measure 2 Questions
1	all	all
2	1, 6	9
3	3, 4	8
4	10-12	2, 5,7

Table 2. Pre/post test Question Measures of Student Learning Outcomes

Learning Goal	Measure	< *g* > non-SL N_{pre}=46, N_{post}=40	< *g* > SL N=14
1	1	32.7	33.6
1	2	32.7	33.6
2	1	37.0	50.0
2	2	42.3	44.4
3	1	18.1	5.26
3	2	59.1	28.5
4	1	24.3	17.2
4	2	40.5	53.3

Table 3. Student Learning Assessment for ASTR 161

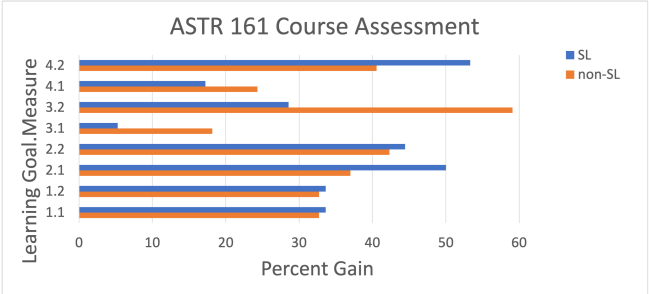

Figure 3. Comparison of assessment outcomes for sections of ASTR 161 The Sky and the Solar System with (N=14) and without (N_{pre}=46, N_{post}=40) a service-learning component

learning section taught within three years of the spring 2022 service-learning class are tabulated below with the spring 2022 results for study participants only (N=14) in Table2 and displayed in Figure3. For the non-service-learning assessment tests, the number of respondents on the pre- and post-tests are 46 and 40, respectively.

Figure 2 shows the distributions of the overall post-test scores for the service-learning and non-service-learning sections. The average post-test scores were 54.2 % and 46.9% for the service-learning and non-service-learning sections, respectively.

Learning goals for all Core 7 courses are specified by the TU Core Course Curriculum Committee:

1. Utilize scientific vocabulary and examples to describe major ideas appropriate to a specific scientific discipline
2. Use quantitative reasoning to analyze and/or support scientific information
3. Identify, describe, critique, respond to and construct the various components of the scientific process such as observations, inferences, operational definitions, aspects of scientific design, conclusions, control of variables, etc.
4. Explain scientific issues of current importance to society within scientific, technological, historical, societal, and ethical contexts.

Table 2 shows the measures from the pre/post-test instrument used to assess each goal.

Class aggregated average gains were calculated using the formula: $<g>= \frac{\%post-\%pre}{100\%-\%pre}$ (Hake, 1998; Prather et al., 2009) where %pre is the percentage of correct responses on the pretest and %post is the percentage of correct responses on the post-test.

Table 3 and Figure 3 show the average gains in both measures of the four learning goals for the service-learning and non-service-learning sections of the ASTR 161 course. For both classes, each measure of the four learning goals meets the goal of at least 10% gain except measure 1 of goal 3 for the service-learning section. Both measures of goal 3 for the service-learning section are lower than for the non-service-learning section.

For learning goal 1 students in the service-learning section of the course had similar learning outcomes to students in the non-service learning section. Both measures for goal 2 are higher, although for measure 2 this is marginal. For goal 4, the picture is mixed, with measure 1 showing a significantly lower gain for the service-learning section and measure 2 showing a significantly larger gain.

5.2 SALG Survey

A Student Assessment of Learning Gains (SALG) provides a view of students' self-assessment of their learning. Students reflect on how course activities, assignments, and resources contributed to building their understanding, skills, confidence, and integration of knowledge in the subject.

A portion of the study participants voluntarily completed an online SALG survey customized for the ASTR 161 Service-Learning course, once at the beginning of the study period (N=6) and again at the end (N=9). SALG Survey questions are given in 10.7 .

SALG survey outcomes are shown in Figures 4 - 7. SALG survey participants showed positive gains in all categories: Understanding (7/7 measures) , Skills (8/8 measures), Attitude (5/6 measures), and Integration (4/4 measures).

The measures with the minimum gain and maximum gain shown in Figures 4 - 7 are listed in Table 4.

The areas of high gain in the student self-assessment, understanding about properties of planets, skills in executing astronomy-related activities, are directly reflective of the service-learning com-

Figure 4. SALG results (N_{pre}=6, N_{post}=9): Understanding

Figure 5. SALG results (N_{pre}=6, N_{post}=9): Skills

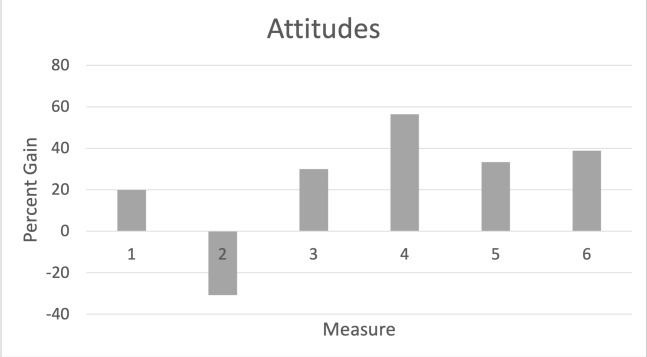

Figure 6. SALG results (N_{pre}=6, N_{post}=9): Attitudes

ponents of the astronomy course. Students gained confidence in the subject matter. Students' self-assessment of their learning about climate change, while still positive, was not as high as in other topics. While the ASTR 161 course did include a lab on the greenhouse effect, this was not a topic involved in the activities that students led for the service-learning component of the course.

Student showed gains in confidence of their understanding of the course subject matter and in their ability to integrate it with other domains of knowledge, although a lower gain in their perception of their ability to integrate the astronomy course material into daily life.

The only SALG measure showing a negative gain was interest in discussing the course subject matter with friends or family. Additional data would need to be collected to explore this result to

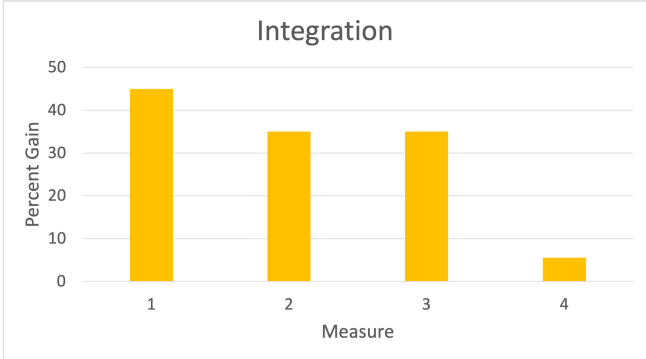

Figure 7. SALG results (N_{pre}=6, N_{post}=9): Integration

Category	Min. Measure	Percent Gain	Max. Measure	Percent Gain
Understanding	How studying this subject helps people address real world issues such as climate change.	35	The formation of the solar system and how this relates to the properties of the planets and the discovery of exoplanets	87
Skills	Critically read articles about issues raised in class	39	Plan and execute astronomy-related activities	77
Attitude	Interested in discussing the subject area with friends or family	-31	Confident that I understand the subject	57
Integration	Using a critical approach to analyzing data and arguments in my daily life	5.5	Connecting key ideas I learn in my classes with other knowledge	45

Table 4. SALG Measures (N_{pre}=6, N_{post}=9)

determine its significance and origin, but it is perhaps indicative of many a course instructor's experience with a fading of initial student enthusiasm for a subject over the course of a semester, especially in introductory courses for nonscience majors.

5.3 Course feedback survey

The optional course feedback survey was administered to students at the end of the semester. It was designed to solicit student opinions on the service-learning experience. The survey questions are listed below, with some excerpts from the overall student comments (N=10). The survey responses were collected anonymously.

What advice do you have for me about the Service-Learning component the next time I teach this class? What worked? What didn't?

- *Leaving the creation of the activities nearly entirely to students I think is a double edged sword.*
- *the opportunity to be able to teach the topics, rather than just*

learn it, was very helpful for solidifying the core concepts of the class
- *preparing for the visit [was] not as much of a priority to some, and could have affected the quality and thought put into the visit.*
- *giving us the freedom to choose our activity was the most fun part!*

What advice do you have for future ASTR 161 Service-Learning students?

- *make sure you understand the content that you plan to talk about*
- *show some enthusiasm, learning about space is actually quite fun.*
- *Plan your activities in advance... Also practice...*
- *Think of ways to capture the students attention when speaking.*
- *Don't be afraid to sit and talk to the students during the activity.*

Did this Service-Learning experience make you think differently about the teaching profession? If so, how?

- *Yes!*
- *...we were able to see first hand how lessons need to be strategically planned and actually take a lot of effort to create.*
- *...i noticed just how natural teaching and interacting with the kids was.*
- *...it made consider how difficult it is to break down complex concepts to a level that elementary students would understand.*
- *I now have even more respect for anyone that can teach, since for me it seems difficult to catch the attention of anyone, let alone a 5th grader!*
- *I have never been in a position of being in front of students, I am a compsci major so we never really have to leave our own bubbles. It was tough at first but the kids are so awesome*

The survey results show that service-learning was viewed positively by students. Students indicated that teaching the content was an effective way to learn the course material. The service-learning experience impacted students' attitudes about teaching. Specifically, they gained appreciation for the preparation involved in teaching and derived enjoyment from the teaching aspect of the course and the interaction with WSA students.

6 Discussion

Dewey (1933) claims that for experiences to be educative, they must promote active engagement between the learner and their environment and be rooted in the learner's interests, values, and prior knowledge. Learning activities that promote reflection and curiosity to learn more will drive a continuous and progressive process of acquiring new knowledge for application to a project that is personally meaningful and socially situated.

By requiring students to apply content knowledge to meet community needs and to engage in reflection and metacognition, service-learning courses are straightforward applications of experiential learning theory. The specific astronomy service-learning project presented here, to support a community after-school program, meets criteria for interaction and continuity while also leveraging the power of learning a subject by teaching it to others.

Finkelstein (2004) showed that a physics content and pedagogy course combined with a community partnership that had students teaching in middle and high schools facilitates student learning of physics content in addition to theories and practices of teaching and learning physics. The course assessment results from this study presented in Section 5.1 show that student learning in astronomy in the ASTR 161 service-learning course was broadly successful, with positive gains in both measures of all learning goals, and all measures except one meeting the goal of 10%. Figure 2 indicates a slight shift towards a higher post-test score distribution for the service-learning section of the course relative to the non-service-learning section. However, a *t*-test does not show a significant difference in the sample means (p = 20%). Figure 3 and Table 3 compare the average gains for specific learning goals. Both measures of goal 3, associated with understanding scientific process, for the service-learning section are lower than for the non-service-learning section. It must be acknowledged that since the contact hours for the service-learning course is the same as for regular sections of the course, the time used for service-learning activities is time that is not used for other learning activities, such as the important active content learning that occurs in laboratory exercises. For goal 4 (explaining scientific issues of societal importance), the service-learning class scored 7% lower for Measure 1 and 13% higher for Measure 2, a mixed result. This discrepancy may be explained by the pre/post-test questions used for each measure, noted in Table 2 and listed in Section 10.6. For Measure 1, the questions relate to the greenhouse effect, solar energy and exoplanets. These topics were covered in both the service-learning and non-service-learning versions of the class and on two laboratory exercises. However, the questions for Measure 2 relate to daily motion of the Sun, solar eclipses, and solar system formation. These topics are more closely tied to the service-learning activities designed and carried out with the WSA students, indicating better learning outcomes for concepts the TU students taught to others through the service-learning component of the course. Gains for goal 1 (using discipline-specific vocabulary) were comparable for both service-learning and non-service-learning classes. Both measures of goal 2, associated with quantitative reasoning, are higher for the service-learning class. This intriguing result requires a larger study for statistical validation, but is broadly aligned with an interpretation of the SALG and optional course feedback surveys from this study through the lens of the work of Follette et al. (2017) showing a strong relationship between quantitative reasoning and student perceptions of numerical self-efficacy and numerical relevancy.

While the number of respondents to the SALG survey was limited (N=6, 9 for the beginning, end of semester survey), students reported that their interest in astronomy was maintained over the semester of astronomy service-learning. With the exception of the decreased interest in discussing astronomy with friends or family noted in Section 5.1, the SALG survey showed positive gains in attitudes about astronomy, i.e. increased confidence in understanding and application of ideas and increased interest in taking additional astronomy classes. Three study participants out of 11 for whom the spring 2022 semester was not their last semester at TU, took another astronomy course that was not required for their major. A limitation of our study and others is the focus on a specific service-learning structure implemented in a single class, resulting in a small sample size (N=14 for the assessment, N<10 for the SALG survey). Similarly, N=13 for the study of Finkelstein (2004). In a mixed-methods study across three science and science communication classses in different disciplines at two universities, Hayford et al. (2014) analyzed student project grades, reflections and self-assessments to infer that service-learning enhances higher order STEM literacy skills. While the study was large (N~1000), the varied classroom and university contexts and the lack of a standardized

measures of learning inhibited robust conclusions. Similarly, a large (N=868) study of a specific service-learning curriculum (Connect Science[2]) at the elementary school level (Rimm-Kaufman et al., 2021) found positive outcomes in science learning and social skills among 4th graders, but pointed to challenges with fidelity of program implementation across the sample.

The intensive logistical effort to implement service-learning results in challenges for sustainability in course instructor workload and relationships with community partners, e.g. as staff members at partner institutions turn over. Future work to expand the study and strengthen statistical significance would require teaching additional service-learning classes and addressing additional challenges in content learning assessment and in coordination and communication with university students and the community partner:

- aligning service-learning activities to meet the needs of the community partner
- scheduling and planning university student visits with the community partner
- clearly communicating service-learning expectations to university students
- clearly communicating culture of community partner (e.g. school dress code) to university students
- university student transportation to community partner

A larger study across multiple institutions would also require aligning service-learning experiences to different contexts, e.g. urban versus rural campuses, for effective and meaningful service-learning. Nevertheless, a model that integrates university students in an after-school program to lead astronomy-based activities is broadly applicable and easily regularized for analysis.

7 Potential implications

Service-learning is designed to have benefits for community partners, but it also comes with specific rewards for participating students, such as community engagement and collaboration with peers. While a much larger study is required to show statistically significant gains, service-learning experiences structured around learning science by teaching can result in improved university student attitudes towards and aptitude in both science content and teaching practice.

The community partner feedback indicated that WSA students gained high satisfaction from their interactions with university students. An unresolved question in this work is how to evaluate whether the community needs as defined by the community partner were met as necessary in a truly reciprocal service-learning collaboration (Jacoby, 1996; Mintz and Hesser, 1996). The WSA after-school program was voluntary for the participating students, and did not need to satisfy any specific curriculum. Activities could thus be driven more purposefully by the WSA student curiosity and questions, listed in Section 10.4. Instead, the TU student-led activities were driven by the course content and the interests of the TU students. The course feedback survey responses reported in Section 5.3 showed mixed reaction to giving students complete freedom to choose the activities. A potential way to address misalignment between community needs (community partner student questions) and content learning goals is to structure activity topics beforehand and guide the initial inquiry of the community partner student questions by the content of the university course. This approach has the potential to give the university students more structure in their choices of activities and to drive additional gains in student content learning by leveraging learning by teaching expectancy Fiorella and Mayer (2013) since university students will know at the time of their own instruction that they will be teaching the topics to others in the service-learning portion of the course.

An interesting area to explore further is the gains in integration of knowledge reported on the SALG survey (Fig. 7). Study participants reported positive gains in their ability to integrate astronomy with other domains of knowledge. The current study data cannot show how service-learning contributes to this gain, but experiential learning theory informs an hypothesis that teaching the subject encouraged students to view abstract topics in astronomy, as not only fascinating but also related to their own daily lives and tangible experiences.

The current study shows that service-learning is a challenging but effective mode of instruction that can be rewarding for both students and instructors. Due to the required reflections on specific and unique class activities, the service-learning model may be more immune to student use of artificial intelligence to generate written responses. The application of this model to a variety of STEM fields also holds great promise for promote authentic learning and positive student experiences..

8 Declarations

8.1 List of abbreviations

1. ASTR: TU subject code for Astrophysics
2. ELT: Experiential Learning Theory
3. SALG: Student Assessment of Learning Gains
4. TU: Towson University
5. WSA: Wolfe Street Academy (community partner)

8.2 Ethical Approval

Students gave informed consent to participate in this research study. To reduce the risk of coercion, a professor not affiliated with the class performed the recruitment and collected consent forms. Consent forms and online survey data were not accessed until after the semester ended and final grades were assigned. To preserve confidentiality, no identifying information is reported in the results.

The project was approved by the Towson University Institutional Review Board.

8.3 Consent for publication

Not applicable

8.4 Competing Interests

The author declares that she has no competing interests.

8.5 Funding

This work was conducted with the support of a Service-Learning Fellowship at Towson University.

2 https://www.connectscience.org

9 Acknowledgements

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10 Appendices

10.1 Partner Memorandum of Understanding

Partners Wolfe Street Academy (WSA) after school program, Ms./Mr. X, Wolfe Street Academy Director of Out of School Time Programming.

Towson University (TU) Instructor, Dr. Jennifer E. Scott, Professor, Department of Physics, Astronomy, and Geosciences, and students in course: ASTR 161: The Sky and the Solar System.

Purpose The goals of this partnership and for TU students in the ASTR 161 Service-Learning course are to gain content knowledge, aptitude, and confidence in science and to improve attitudes toward science education on the part of nonscience majors, with an objective of attracting students to the teaching profession.

Expectations As part of a Service-Learning curriculum in the ASTR 161 course, Towson University students will perform 4-5 activities with students in the Wolfe Street Academy after school program over February – May 2022. Prior to their visits to WSA, TU students will be provided with background information on WSA as a school, and on the population of WSA student participants in the after-school program they will be visiting.

Dr. Scott will communicate the importance of professionalism to the TU students in their interactions with WSA students and staff. Professionalism, including promptness, use of appropriate language, and encouraging and respectful interactions with WSA students, will be a component of the overall score that TU students earn in their Service-Learning course.

Per TU requirements, Dr. Scott and TU students will be vaccinated against COVID-19 or will undergo regular testing. Dr. Scott and TU students will follow COVID-19 masking protocols as required by TU and by WSA. Dr. Scott and Ms./Mr. X will engage in ongoing communication about the TU-WSA student engagement and about the partnership's progress towards meeting the learning goals of both the TU and WSA students.

Dr. Scott will solicit feedback from Ms./Mr. X about the teaching performance of the TU students and the overall effectiveness of the TU student led activities from the perspective of WSA students.

Outcomes TU students will gain course appropriate content knowledge in astronomy by leading WSA students in age-appropriate science activities.

WSA students will gain knowledge of astronomy and excitement about pursuing future education in STEM subjects.

10.2 Service-Learning Student Agreement

The Service-Learning component of this course will be most effective for both TU students and for Wolfe Street Academy students if all ASTR 161 students are committed to the success of the partnership.

I understand that the visits to Wolfe Street Academy are mandatory components of this course and that excused absences for the planned activities at WSA will only be granted in exceptional circumstances. [Respond by entering your full name]

I understand that while we will endeavor to carpool as much as possible, I am ultimately responsible for my own transportation to/from Wolfe Street Academy on the dates of the visits. [Respond by entering your full name]

I have read and I understand the guidelines for student conduct and safety outlined in the Information section of this Blackboard site and I agree to abide by them. [Respond by entering your full name]

10.3 Service-Learning Expectations and Guidelines for Students

Course Expectations Our community partner for the Service Learning portion of the course is After School Program at Wolfe Street Academy. WSA is a Title 1 Community School in Baltimore City, near Patterson Park. We'll be learning more about it as we prepare for our first visit.

Over the semester, we will make 5 visits to the school to do activities with the 5th grade students in the program. The activities will align with the content of the course, described on the syllabus. Part of your grade for the course will be based upon the Preparation, Execution, and Reflection for each visit. Those components are described in the Assignments section of this Blackboard site.

This is general logistical information about the school and the visits:

- Students are required to provide their own transportation to the school site. We will arrange carpooling as best we can, but you should not depend on these arrangements.
- The school address is 245 S Wolfe Street, Baltimore, MD 21231. If you put this into your GPS, it will lead you to the main entrance of the school, which is on S Wolfe Street. Please enter through this door.
- The school does not have a parking lot. There is free, unmetered parking on the blocks surrounding the school. There's parallel parking on S. Wolfe and S. Ann Streets, and some back-in parking on Gough and Bank Streets.
- When you arrive at the main entrance, ring the doorbell that is on the wall to your left. You will then be granted access to the building.
- Please check in at the front office. It is the first door on your left when you enter the school. The front office staff will show you the sign-in binder and give you a visitor pass. Ms. X's office is located in the front office suite.
- All Baltimore City Schools require the use of masks at all times in the school building. Please be sure to wear your mask properly when you enter the school.
- In these visits, you are representing Towson University in the community. A portion of your Execution grade for each school visit activity will be based on following these conduct guidelines.

Student Conduct TU students are expected to conduct themselves in a professional manner while on site at Wolfe Street Academy by:

- Being punctual for all visits and attending them for the duration.
- Communicating promptly with your course instructor about any logistical problems you encounter.
- Adhering to all school rules, including the requirement for masking noted above. Interacting with students and school staff in a respectful manner.

- Wearing appropriate attire that conforms to the WSA dress code:
  - No low-cut shirts, crop-tops, or see-through tops (unless they have a tank or full-coverage shirt underneath).
  - Shorts and skirts should reach at least the length of the fingers when arms are held down to one's sides.
  - Tank tops should cover the shoulder (no spaghetti straps).
  - No clothing with vulgar or suggestive language or images.
  - No clothing with rips or tears.

Students should never:

- Report to WSA under the influence of drugs or alcohol.
- Give or loan money or other personal belongings to a WSA student or staff member.
- Make promises or commitments to a WSA student or staff member that neither the student nor TU can keep.
- Give a WSA student or staff member a ride in a personal vehicle. DO NOT transport a child by yourself.
- Tolerate verbal exchanges of a sexual nature or engage in behavior that might be perceived as sexual with a WSA student or staff member.
- Tolerate verbal exchanges or engage in behavior that might be perceived as discriminating against an individual on the basis of age, race, gender, sexual orientation, or ethnicity.

Student Safety Safety precautions students should take when working in an area they are unfamiliar with:

- Keep your automobile a non-attraction.
- Do not leave items visible in the car's interior.
- Place valuable articles in the trunk prior to arrival.
- If you take the bus, be sure to know the route and the bus fare. In case of a breakdown or transportation problem, carry enough money to get home.
- Develop a community safety net of resources in your placement area.
- Get to know your supervisor at the agency. Ask her/him questions about the area and get suggestions on what you should do if you find yourself in trouble.

10.4 Questions Posed by WSA Students

- Who names the planets?
- What kinds of telescopes do we use? How do they work?
- What is astronomy?
- Are there moons around other planets and other suns? Why are there moons around planets?
- Why does only Earth have life?
- What do the planets look like?
- What is the difference between dwarf planets, asteroids, comets?
- Where and how do planets form
- What happens to organic material in space? Would it decompose?
- How do black holes form?
- How did Earth get water?
- Has anyone found a new planet? Are there infinite planets?
- How do we find galaxies?
- Who named the galaxies and why is ours called the Milky Way?
- How did the Moon form?
- What is the heaviest thing in the solar system?
- What else exists in space other than planets?
- Is there a planet where it rains diamonds?
- Can you figure out date and time in space or on another planet?
- How long is a Mars day?
- Who has traveled furthest from Earth?

10.5 Student Service-Learning Reflection Questions

Preparation

Lead Group: In your own words, give a short explanation of the next planned activity at Wolfe Street Academy.

Other Groups: Give a specific description of your group's role in the next planned activity at Wolfe Street Academy and your planned contribution(s).

Reflection

What was your team's role in the activity for this visit? What specific part did you play? [Respond in 1-3 complete sentences]

How was the activity an accurate conveyor of scientific concepts? In what ways could it be made more accurate? [Respond in 1-5 complete sentences]

Was the activity effective for engagement and learning on the part of WSA students? Give specific evidence. [Respond in 1-5 complete sentences]

How would you change the activity if you were to plan and do it again? [Respond in 1-5 complete sentences]

What did you learn about the content of the activity that you did not know or fully understand prior to the visit to WSA? [Respond in 1-5 complete sentences]

Give two possible test questions about the content of the activity performed in the last visit: for WSA students for this course (i.e. for TU students like yourself). You can use any format for the questions but you must give a key (i.e. indicate the correct answer).

Optional additional reflections, not covered by the questions above. [May earn up to 3 extra credit points for this exercise.]

Assessment

This form is to be completed only by the Assess Group for each visit. Some assessment feedback may be shared with the Lead, Equip, and Assist Groups but your responses will remain confidential.

Be honest but also constructive. Remember that all peer classmates will evaluate each other over the course of the semester.

The Lead Group's role was to design and lead the activity, inform the Equip group of their material and equipment needs, assign the Assist group their roles.

- In 1-3 sentences, give an example of one aspect of the Lead Group's execution of their role that worked very well, in your judgment. Give specific evidence.
- In 1-3 sentences, give an example of one aspect of the Lead Group's execution of their role that could be improved in a future activity, in your judgment. Give specific evidence."

The Equip Group's role was to acquire the materials and equipment needed (with the help of the instructor) and transport it to the program site on the day of the activity, monitor throughout the activity, and clean up and transport back as necessary after the activity.

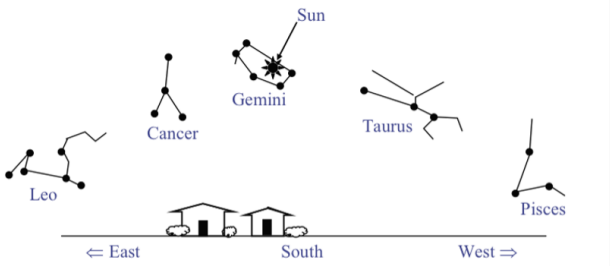
- In 1-3 sentences, give an example of one aspect of the Equip Group's execution of their role that worked very well, in your judgment. Give specific evidence."
- In 1-3 sentences, give an example of one aspect of the Equip Group's execution of their role that could be improved in a

future activity, in your judgment. Give specific evidence."

10.6 ASTR 161 The Sky and the Solar System Assessment Test

Several questions on this course assessment test were derived from the Astronomy Diagnostic Test (Hufnagel, 2001).

1. Radio waves travel at .
   a) a speed less than the speed of light, about 300 meters/second
   b) the speed of light (c =3 × 10^5 meters/second)
   c) the speed of light (c=3 × 10^8 meters/second)
   d) a speed more than the speed of light (3 × 10^{10} meters/second)
2. If you could see the stars during the day, the drawing below shows what the sky would look like at noon on a given day. In the drawing, the Sun is near the constellation of Gemini. Near which constellation would you expect the Sun to be located at sunrise?
   a) Leo
   b) Cancer
   c) Gemini
   d) Taurus



3. Imagine that the Earth's orbit is changed to be a perfect circle around the Sun, so that the distance to the Sun never changed. How would this affect the seasons?
   a) We could continue to experience seasons in the same way we do now
   b) We would still experience seasons, but the difference would be far less noticeable
   c) We would no longer experience any difference between the seasons
   d) We would still experience seasons, but the difference would be far more noticeable
4. Which of the following is an advantage of using a telescope in space as compared to a telescope of the same size on the ground?
   a) It is not affected by chromatic aberration.
   b) It can achieve better spatial resolution.
   c) It is less expensive to build and operate.
   d) It is closer to the object being observed.
5. When the Moon appears to completely cover the Sun (a solar eclipse), the Moon must be at which phase?
   a) Full
   b) New
   c) First quarter
   d) At no particular phase
6. If Mars is 1.5 × 10^8 km from Earth, how long does it take radio signals from the Curiosity rover to reach us? (the speed of light is about 3 × 10^5 km/sec)
   a) 8 minutes
   b) 3.26 years
   c) 26,000 years
   d) 150,000 years
7. The most likely mechanism for the solar system's formation is
   a) the Sun captured the planets as they drifted through space
   b) the planets spun out of the Sun as smaller clouds and then condensed
   c) the planets are the remains of another star that was broken up inside the Sun's Roche limit
   d) the Sun and planets condensed from a gas and dust cloud
8. As viewed from our location, the stars of the Big Dipper can be connected with imaginary lines to form the shape of a pot with a curved handle. To where would you have to travel to first observe a considerable change in the shape formed by these stars?
   a) Across the country
   b) A distant star
   c) Moon
   d) Pluto
9. An asteroid orbits the sun in a circle with a period P of 12 years. About how far from the Sun is it? (Remember that $P^2 = a^3$, and the Earth goes around the Sun with P = 1 year and a = 1 AU)
   a) 50 AU
   b) 12 AU
   c) 10 AU
   d) 5 AU
10. Why is the amount of carbon dioxide in the atmosphere important for life on Earth?
    a) An excess will increase global temperatures, and a shortfall will result in a frozen Earth.
    b) An excess will result in a frozen Earth, and a shortfall will increase global temperatures.
    c) An excess will destroy the ozone layer, and a shortfall will create too much ozone.
    d) An excess will create too much ozone, and a shortfall will destroy the ozone layer.
11. The Sun's energy comes from
    a) the combining of light elements into heavier elements
    b) the breaking apart of heavy elements into lighter ones
    c) chemical reactions
    d) contraction
12. Of the thousands of extrasolar planets detected so far, most are
    a) Jupiter-sized and closer to the parent star than Jupiter is to the Sun
    b) Jupiter-sized and further from the parent star than Jupiter is from the Sun
    c) super Earth-sized and closer to the parent star than Earth is to the Sun
    d) super Earth-sized and further from the parent star than Earth is from the Sun

10.7 Student Assessment of Their Learning Gains

Understanding: Presently, I understand...

1. The following concepts that will be explored in this class
2. Motions of the Sun, Moon and stars in the sky over a day,

month, and year
3. Properties of electromagnetic radiation and how we detect it
4. The formation of the solar system and how this relates to the properties of the planets and the discovery of exoplanets
5. The cause of the greenhouse effect and how it influences the surface temperature of a planet
6. How ideas we will explore in this class relate to ideas I have encountered in other classes within this subject area
7. How ideas we will explore in this class relate to ideas I have encountered in classes outside of this subject area
8. How studying this subject helps people address real world issues such as climate change.

What do you expect to understand at the end of the class that you do not know now?

Skills: Presently, I can...

1. Find quality sources relevant to a particular teaching strategy or topic in astronomy.
2. Critically read articles about issues raised in class
3. Identify patterns in data
4. Recognize a sound argument and appropriate use of evidence
5. Develop a logical argument
6. Plan and execute astronomy-related activities
7. Work effectively with others
8. Prepare and give oral presentations

What do you expect to be able to do at the end of the course that you cannot do now?

Attitudes: Presently, I am...

1. Enthusiastic about the subject
2. Interested in discussing the subject area with friends or family
3. Interested in taking or planning to take additional classes in this subject
4. Confident that I understand the subject
5. Confident that I can do this subject
6. Comfortable working with complex ideas

Please comment on your present level of interest in this subject.

Integration of Learning: Presently, I am in the habit of...

1. Connecting key ideas I learn in my classes with other knowledge
2. Applying what I learn in classes to other situations
3. Using systematic reasoning in my approach to problems
4. Using a critical approach to analyzing data and arguments in my daily life

Please comment on how you expect this material to integrate with your studies, career, and/or life?

GPA

1. What is your current GPA in a system that assumes a 4.00 as an A (highest score possible)?
2. My GPA is...

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