

Enhancing student engagement and performance in high school astronomy through a differentiated homework approach

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Abstract. Astronomy education at the high school level faces challenges in motivating students and addressing their diverse learning needs. Traditional homework often involves rote memorization and fails to engage students meaningfully with astronomy concepts. This paper presents an innovative approach to astronomy homework that incorporates differentiation, student choice, use of information technology, and a mix of standard problems and creative tasks. The approach was implemented with 49 grade 11 students in Ukraine. Although efficacy data is limited, teacher observations and student feedback indicate that differentiated homework enhanced engagement, effort, and conceptual understanding compared to traditional methods. Students completed more assignments and produced higher-quality work. Notably, students displayed more interest in astronomy and took greater ownership of their learning. Key components of the differentiated homework were the use of multi-modal tasks, real-world applications, collaborative activities, and integration of digital tools and online resources. Some challenges included the time required for individualized grading and the need for support to help teachers adapt their practices. This approach provides a promising model for transforming astronomy education to be more student-centered, active, and inclusive. With adaptation, it could potentially be applied across STEM disciplines.

Keywords: astronomy education, differentiated instruction, homework, active learning, student engagement, educational technology

1. Introduction

Astronomy is a fascinating and rapidly advancing field of science, but many high school students find astronomy classes unengaging and disconnected from their interests and experiences [1, 30]. A key challenge is the way astronomy is often taught, with a heavy emphasis on memorization of facts and lack of opportunities for active learning and exploration [25]. This is particularly evident in homework assignments, which are a central part of the learning process and consume much of students' time and effort [6]. Research suggests traditional homework in astronomy and other science classes tends to be repetitive, passive, and decontextualized from real applications [10, 26]. This style of homework contributes to many students becoming disengaged from astronomy. International studies have documented that students view school astronomy as difficult and uninteresting [1, 11, 21]. Even students who are drawn to astronomy often lose interest as they progress through secondary school [11, 26, 30]. The problem is compounded for students who struggle academically or come from groups underrepresented in science [6, 25].

There is a clear need to rethink astronomy homework to make it more meaningful,

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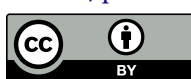
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relevant, and adapted to students' diverse knowledge, skills, and interests. Promising strategies from education research include differentiated instruction, active and collaborative learning, real-world connections, and technology integration [2, 3, 15, 32]. Differentiated instruction involves tailoring content, process, products and learning environments to students' readiness levels, interests, and learning profiles [6, 27]. The goal is to provide appropriate levels of challenge and support to enable all students to succeed [9, 24, 29]. Active learning engages students in constructing knowledge through activities such as experiments, problem-solving, and discussion, rather than just passively receiving information [5, 8, 15]. Collaborative learning involves students working together on shared goals, which can increase motivation, understanding, and social skills [3, 26, 27]. Real-world connections help students appreciate the relevance of what they're learning to their lives and potential STEM careers [8, 13, 17]. Finally, technology can expand learning opportunities, facilitate individualization, and develop 21st century skills [5, 24, 32].

Despite the potential of these strategies, there are relatively few examples of their application to high school astronomy education in the literature [6, 11]. Some studies have examined the benefits of specific instructional approaches, such as use of planetariums [7], teaching with models [16], and integrating astronomy and physics concepts [9]. Others have tested technology-based interventions such as use of robotic telescopes [10], virtual laboratories [24], and digital storytelling [5]. A handful of initiatives have developed structured astronomy curricula incorporating hands-on activities, inquiry-based learning, and links to real scientific research [8, 14, 32]. However, there remains a lack of research on homework practices in high school astronomy and how they can be designed to support different learners' needs and promote engagement [5, 26].

This paper addresses this gap by presenting a differentiated approach to astronomy homework implemented in a Ukrainian high school context. The homework was designed to give students choice in learning activities, incorporate authentic applications of astronomy, integrate technology meaningfully, and balance structure with opportunities for creativity. The goal was to examine how a student-centered homework approach influenced engagement, effort, and performance in astronomy class.

2. Literature review

2.1. Engagement and equity issues in high school astronomy education

Astronomy is a part of the science curriculum in many countries, but the quality of high school astronomy education varies widely [1, 25, 28]. A international review by Fitzgerald et al. [11] found that astronomy content is often minimal, fragmented, and outdated in high school curricula. Instruction tends to focus on memorization of facts rather than conceptual understanding, scientific reasoning, and connections to students' lives and society [16, 30]. There is often a disconnect between school astronomy and methods used by practicing astronomers, such as modeling, data analysis, and use of technological tools [14, 26]. Consequently, many students develop misconceptions and negative attitudes towards astronomy [7, 28]. A study across multiple countries found that 16-18 year olds had a poor grasp of basic astronomy concepts and did not see the relevance of astronomy to their futures [21].

Student engagement in high school astronomy is a widespread problem [11]. A survey of nearly 1,500 Australian students found that the majority were uninspired by their astronomy classes and perceived instruction as boring and repetitive [6]. Only around 20% said they would consider a career in astronomy. Fitzgerald et al. [11] attributes this disengagement to factors including the low priority given to astronomy

in school timetables, lack of qualified specialist teachers, and limited resources and equipment. Marušić and Hadžibegović [21] notes that lack of opportunities for practical, hands-on experiences with real astronomical tools and data is a key problem. Many students see astronomy as an abstract subject disconnected from the real world [28].

Compounding the overall disengagement issue are inequities in access, participation, and achievement in astronomy education [3, 6, 25]. Female students tend to express less interest and self-efficacy in astronomy compared to male peers, likely due to societal stereotypes and lack of role models [7, 26]. Students from racial and ethnic minority groups, low-income families, and rural areas often have fewer opportunities to learn astronomy in school or through informal experiences [3, 11, 13]. Students with disabilities encounter challenges with inaccessible instruction, materials, and technologies [18]. English language learners may struggle to engage with astronomy content presented in a non-native language [5]. Achievement gaps along demographic lines are apparent in astronomy assessments internationally [21, 25, 28]. Making astronomy education more equitable requires attending to cultural, linguistic, and ability diversity among learners [9].

The problems of student disengagement and inequity in astronomy education are complex, but research suggests that instructional practices play an important role [11]. Traditional lecture-based, textbook-centered methods that dominate high school astronomy classrooms are misaligned with research on how people learn [16, 25]. There is a need to shift towards more student-centered, active approaches that build on learners' prior experiences, provide appropriate supports and challenges, and develop transferable skills and knowledge [3, 7]. Homework is a key area where such approaches can be implemented, as it makes up a significant portion of course time and influences students' studying habits [6].

2.2. Differentiated instruction in science and astronomy education

Differentiated instruction is an approach that adapts teaching to individual students' needs in order to maximize their learning [9, 24, 27]. It is grounded in the understanding that students vary widely in their background knowledge, skills, interests, and learning preferences [6]. Differentiation can involve modifications to the content students learn, the process by which they learn it, the products they create to demonstrate learning, and/or the environment in which learning takes place [23]. The goal is to provide all students with appropriately challenging learning experiences that enable them to progress [3].

In the context of science education, differentiation often entails using flexible grouping, tiered assignments, interest-based projects, and diverse instructional strategies to accommodate student differences [23, 27]. For example, a teacher might pre-assess students' understanding of a concept and provide leveled texts and activities to different groups based on their readiness [24]. They might allow students to choose from a menu of project options aligned with their interests and talents [9]. They might use visual, auditory, and kinesthetic modes of instruction and expression to suit various learning styles [32]. Differentiation can also involve modifying the pacing, amount of structure, and level of independence in learning tasks based on students' needs [23]. Technology tools are often used to facilitate individualization [5].

Research suggests that differentiated science instruction can improve students' engagement, understanding, and achievement [9, 23, 24]. A study by Susilawati et al. [27] documented enhanced scientific reasoning among students who experienced differentiated, inquiry-based physics instruction. Interviews indicated students felt more challenged and supported to learn in a differentiated classroom.

Scholars have argued that differentiation is especially important in astronomy

education, given the diversity of students' prior experiences and the need to address alternative conceptions [25, 28]. Many students come to astronomy with limited exposure to key concepts and may struggle to grasp abstract ideas about space, time, and scale [7]. At the same time, some students have quite advanced knowledge from outside interests and experiences [11]. A one-size-fits-all approach fails to support either group effectively. Differentiation allows teachers to build on each student's starting point and provide targeted scaffolding [23].

However, studies indicate that differentiated instruction is not widely used in high school astronomy [4, 11, 26]. Large class sizes, pressure to cover extensive curriculum standards, and limited resources make individualization challenging. Many astronomy teachers have not had professional development on differentiation strategies [23]. There is a need for more research and practical examples of how differentiation can be implemented in astronomy classrooms [11, 25].

Some promising work has begun to emerge. Pössel [24] describes an approach to teaching cosmology concepts using piecewise inertial frames, a simplified model that allows students to explore ideas at different levels of complexity. Aroca and Silva [3] reports on a differentiated instructional sequence for teaching about the Sun, with activities adapted to students' skill levels and interests. Vaquerizo [32] developed an online astronomy course that uses adaptive technology to personalize learning paths. These studies provide glimpses of the potential of differentiation, but more comprehensive models are needed.

2.3. Active learning through authentic astronomy practices

Alongside differentiation, active learning is a key strategy for increasing student engagement and conceptual understanding in astronomy [11, 26]. Active learning involves students directly constructing knowledge through experiences such as experimentation, problem solving, analysis, and discussion [3, 9]. Rather than passively receiving information, students engage in sense-making and reasoning processes similar to those used by scientists [8]. Research across STEM fields has shown that active learning improves motivation, reduces misconceptions, and leads to deeper, more transferable knowledge compared to traditional lecture [12, 26].

In astronomy education, active learning often involves students participating in authentic scientific practices such as observation, data collection, modeling, and argumentation [2, 11, 25]. Hands-on activities with telescopes, spectrographs, and celestial globes allow students to explore phenomena directly [3, 32]. Analysis of real astronomical datasets develops skills in visualization, pattern-finding, and inference [2, 10]. Student-led investigations, either individually or in groups, provide opportunities to pose questions, develop hypotheses, and construct evidence-based arguments [8, 17]. By engaging in these practices, students begin to think and work like astronomers.

Authentic learning experiences have been shown to increase high school students' astronomy engagement and performance. For example, Fitzgerald et al. [10] studied the impact of a semester-long astronomy course that engaged students in a full cycle of the research process using a remote telescope. Students developed their own research questions, collected and analyzed data, and communicated findings in presentations and papers. Compared to a traditional astronomy curriculum, students in the research intervention made significantly greater gains in content knowledge and scientific reasoning skills. They also expressed more positive attitudes towards astronomy and science careers.

Similarly, a study by Etkina, Matilsky and Lawrence [8] engaged high school students in authentic astrophysics investigations through a summer enrichment program. Working with astronomer mentors, students learned to use real data from space telescopes and ground-based observatories to study questions about galaxy evolution

and stellar populations. Pre- and post-assessments revealed strong growth in students' abilities to interpret data, develop models, and justify claims with evidence. Students reported increased interest and confidence in pursuing astronomy research.

Other active learning astronomy interventions have focused on specific practices such as observation [3], data analysis [2], and modeling [24]. These targeted experiences, while narrower in scope, can still effectively develop skills and stimulate interest. For instance, Aroca and Silva [3] describes an approach to teaching about sunspots that involved students making daily observations of the Sun, recording data, and identifying patterns. Students showed gains in understanding of sunspot formation and the Sun's rotation. Interviews indicated the observational activities made the astronomy content more concrete and memorable.

While active learning holds much promise, challenges remain in implementing it equitably and efficiently. Authentic inquiry takes time and may require specialized equipment or datasets that not all schools have access to [11]. Teachers need substantial training to facilitate open-ended investigations and adapt to the student-centered instructional role [26]. Careful scaffolding is needed to ensure all students, including those with less prior experience or skill, can participate meaningfully [23]. The approach must also align with curriculum standards and high-stakes assessments [11].

2.4. Technology integration in astronomy teaching and learning

Technology is an essential part of modern astronomy, and astronomers rely on a range of digital tools for observation, data collection, analysis, modeling, and communication [32]. Reflecting this, the integration of technology has been a major trend in astronomy education in recent years [5, 26]. When used effectively, technology can enable students to access real astronomical data, visualize complex concepts, collaborate with peers and experts, and create multimedia products to demonstrate their learning [4, 11, 24].

One prominent example is the use of robotic telescopes, which allow students to remotely control research-grade instruments to gather data on celestial objects [10, 32]. Studies have found that engaging in authentic investigations using these telescopes can significantly enhance students' astronomy knowledge, motivation, and attitudes towards science [11, 17]. For instance, Fitzgerald et al. [10] found that high school students who used a remote telescope to study variable stars made greater gains in conceptual understanding and inquiry skills compared to a traditional astronomy curriculum.

Digital simulations and virtual labs are another promising technology for astronomy education. These interactive environments allow students to manipulate variables, test predictions, and visualize systems in ways impossible with physical equipment [24, 27, 31]. Research suggests simulations can be effective for teaching complex topics such as gravity, light, and spectra [4, 24]. A study by Susilawati et al. [27] found that pre-service teachers who used a virtual astronomy lab to conduct observations and experiments showed improved scientific reasoning skills. However, the authors note that guidance and reflection are needed to ensure simulations build accurate conceptual models.

Mobile and web-based technologies have also been used to support astronomy learning in and out of the classroom. Smartphones and tablets with GPS, compass, and camera capabilities can serve as portable observation and data collection tools [22]. Astronomy apps and software can help students identify celestial objects, chart the motion of the Sun and Moon, and explore astrophysical concepts [5, 32]. For example, the Sky Map app allows users to hold up their phone to the sky and see a dynamic map of visible stars, constellations, and planets. Chubko et al. [5] found

that English language learners who used Sky Map and other astronomy apps to support a digital storytelling project showed increased engagement and conceptual understanding.

Online citizen science platforms are another way to connect students with authentic astronomy research [2, 11]. Projects such as Galaxy Zoo, Planet Hunters, and Sungrazer invite volunteers to classify galaxies, search for exoplanets, and track solar activity using professional datasets [22]. Participation can develop students' content knowledge, data analysis skills, and appreciation for the process of science [2]. However, Fitzgerald et al. [11] cautions that citizen science projects must be carefully integrated with curriculum goals and provide appropriate training to be effective learning experiences.

Despite the potential benefits, technology integration in astronomy education also presents challenges. Many schools lack funds for specialized software and equipment, and students may have uneven access to devices and internet at home [9, 26]. Teachers need time and training to learn new technologies and integrate them meaningfully into instruction [1, 32]. Technical difficulties can derail lessons and frustrate students [4]. Moreover, technology should enhance, not replace, hands-on experiences and direct observation of the sky [26]. Careful instructional design is needed to ensure technology use is purposeful, supports learning goals, and is accessible to all [31].

2.5. Research gaps

The literature review has highlighted both the challenges and opportunities in high school astronomy education. Engaging all students meaningfully in astronomy learning remains difficult due to factors including traditional instruction, limited resources, and lack of authentic experiences [11, 26]. Homework is a key area where these challenges manifest, with many astronomy assignments emphasizing rote memorization over deep understanding and real-world connections [6]. Reforming homework practices is thus a priority for making astronomy more relevant and equitable.

Research provides evidence for the promise of instructional approaches involving differentiation [3, 27], active learning [8, 10], and technology integration [2, 5, 24]. These strategies can increase student engagement, reduce misconceptions, develop scientific skills and reasoning, and provide opportunities for choice and self-direction [9, 23]. Examples of their application in astronomy education are beginning to emerge, but more studies in real classroom contexts are needed [6, 26].

This paper addresses these research needs by presenting a comprehensive approach to homework in a high school astronomy course. Grounded in educational theory and prior empirical work, the differentiated homework aimed to increase student engagement and performance through a combination of elements: 1) personalized options to accommodate diverse interests and skills, 2) authentic astronomical practices and real-world data, and 3) integration of technological tools and resources.

3. Homework design and implementation

3.1. Context and participants

The differentiated homework approach was implemented in two Grade 11 astronomy classes at a public high school in an urban area of Ukraine. The school serves a socioeconomically and academically diverse student population. Astronomy is a one-semester elective course that meets for 45 minutes per class, three times per week.

The study participants included 49 students (28 female, 21 male) aged 16–17 years old. The students exhibited a range of prior achievement levels and interest in science

based on their performance in previous physics and mathematics courses. Three students were identified as academically gifted, while five were at risk of course failure.

The astronomy course was taught by a teacher with 7 years of experience and a specialization in physics and astronomy education. The teacher had previously used some active learning strategies such as hands-on activities and demonstrations, but the course relied heavily on lectures and textbook-based assignments. The teacher was interested in exploring new instructional approaches to increase student engagement and provide more individualized support.

3.2. Homework design process

The differentiated homework approach was co-designed by the astronomy teacher and the author, an education researcher with expertise in differentiated instruction and technology integration. The process began by examining the existing astronomy curriculum and identifying key topics and learning objectives for each unit. Particular attention was paid to areas where students typically struggled or disengaged, based on the teacher's experience and prior course evaluations.

For each unit, a set of "core" homework tasks was developed to provide a common foundation and formatively assess student understanding. These included a mix of questions from the textbook, short answer prompts, problem sets, and online quizzes. The core tasks were designed to be accessible to all students while still providing opportunities for critical thinking and application.

To provide differentiation, a menu of "challenge" tasks was also created for each unit. These tasks offered students choice in content focus, process, product, and level of difficulty. They included options such as:

- conducting independent research on a topic of interest and presenting findings to the class;
- analyzing real astronomical data using online tools and creating a report;
- designing a physical or digital model to illustrate a concept;
- developing an lesson plan to teach a younger student about a phenomenon;
- writing a news article about a recent astronomical discovery for a public audience.

The challenge tasks were designed to push students to extend and apply their learning in authentic ways. They incorporated authentic astronomy practices such as observation, data analysis, modeling, and communication. Rubrics and exemplars were provided to communicate expectations and support self-assessment.

Technology was integrated throughout the homework to provide access to data, tools, and resources. Online platforms such as Google Classroom and Moodle were used to deliver assignments, facilitate collaboration, and provide feedback. Links to astronomy databases (e.g. Sloan Digital Sky Survey), citizen science projects (e.g. Galaxy Zoo), and simulation software (e.g. Stellarium) were embedded in specific tasks. Students could use personal devices or school computer labs to complete technology-based assignments.

Accommodations were built into the homework design to support diverse learners. Tasks were presented in multiple formats (e.g. written, video, audio) and difficulty levels. Enlarged print and tactile/auditory options were available for visually impaired students. The teacher offered extra help sessions and individual check-ins to assist struggling students.

The homework approach was iteratively refined based on student feedback and performance data. For example, some challenge tasks were adjusted to provide more structure or align better with available resources. The pacing of assignments was modified to allow more time for complex projects. New tasks were added to target

identified misconceptions or skill gaps. The goal was to continuously improve the homework to better meet students' needs and promote meaningful astronomy learning.

3.3. Homework implementation

The differentiated homework approach was implemented over a 15-week semester. Students were given a homework guide at the beginning of each unit outlining the core and challenge tasks, due dates, and grading criteria. The teacher introduced the guide and discussed the purpose and expectations for homework.

Core tasks were assigned to all students and typically due within 1-2 weeks. Brief quizzes or reflections at the beginning of class were used to check students' completion and understanding of the core content. The teacher reviewed common questions and misconceptions before moving on to new material.

Challenge tasks were assigned every 2-3 weeks and students had choice in which task(s) to complete. Students were encouraged to try a variety of task types and difficulty levels over the semester. They could work individually or in small groups, and some class time was allocated for collaboration and teacher feedback. Students submitted challenge tasks via Google Classroom or email.

The teacher provided formative feedback on all submitted homework, either individually or to the class as a whole. Common errors and exemplary work were discussed to help students learn from each other. Students had opportunities to revise and resubmit select assignments for additional credit and to track their progress.

Homework was graded based on completion, effort, and demonstration of proficiency. Core tasks were awarded points based on accuracy and thoroughness, with opportunities to correct mistakes. Challenge tasks were evaluated with rubrics emphasizing scientific practices, conceptual understanding, and communication. Final homework grades were calculated as an average of all submitted assignments.

Technology was used to support homework implementation in several ways. The teacher created instructional videos to introduce key concepts and demonstrate use of online tools. Links to supplementary resources and tutorials were posted on the class website. Students used collaborative tools like Google Docs and Padlet to brainstorm ideas and give each other feedback. Online assessments provided instant scoring and targeted review. The teacher used the learning management system to track student progress and identify areas for individual support.

Differentiation and flexibility were maintained throughout the semester. The teacher made adjustments based on student interest, progress, and real-world events. For example, a new challenge task was added for students to analyze data from a recent lunar eclipse that generated media attention. Extra scaffolding was provided for a group project when it became apparent students needed more structure. Alternative formats were created for some assignments to accommodate different learning preferences.

The homework implementation required significant time and effort from both the teacher and students. The teacher dedicated several hours per week to creating assignments, providing feedback, and troubleshooting technical issues. Students reported spending an average of 2-3 hours per week on astronomy homework, with some investing considerably more time in challenge tasks. Ongoing communication and support were necessary to maintain engagement and progress.

4. Results

The differentiated astronomy homework implemented in the study incorporated a wide variety of task types, formats, and modalities to engage students' diverse interests, skills, and learning preferences. The assignments were designed to provide multiple

pathways for students to access and express their understanding of astronomical concepts and phenomena.

One common type of homework task involved completing diagrams, tables, and other graphic organizers related to key course topics. For example, students were given a table listing famous astronomers throughout history and asked to fill in each scientist's most notable achievement or discovery, as shown in table 1. This activity aimed to help students connect major figures to their contributions and situate them within the broader narrative of astronomy as a field. Completing the table required students to distill their knowledge into concise statements, promoting a focus on essential ideas.

Table 1

Astronomer and achievement.

Astronomer	Achievement
 Claudius Ptolemy	Developed the geocentric model of the solar system with planets moving in epicycles
 Nicholas Copernicus	Proposed the heliocentric model with the Sun at the center and planets orbiting in circles
 Johannes Kepler	Discovered the three laws of planetary motion, which describe the elliptical shape and speed of orbits
 Galileo Galilei	Used telescopes to observe the phases of Venus, moons of Jupiter, and sunspots, supporting heliocentrism

Another graphic-based task had students label a diagram of the solar system and arrange the planets in order of their distance from the Sun, as in figure 1. This

exercise targeted student comprehension of the scale and structure of our local cosmic neighborhood. By filling in the planet names and ordering them appropriately, students could demonstrate their grasp of the relative positions and spacing of solar system objects. For students who benefit from visual representations of information, this task provided a concrete way to process and communicate their mental model of the solar system.

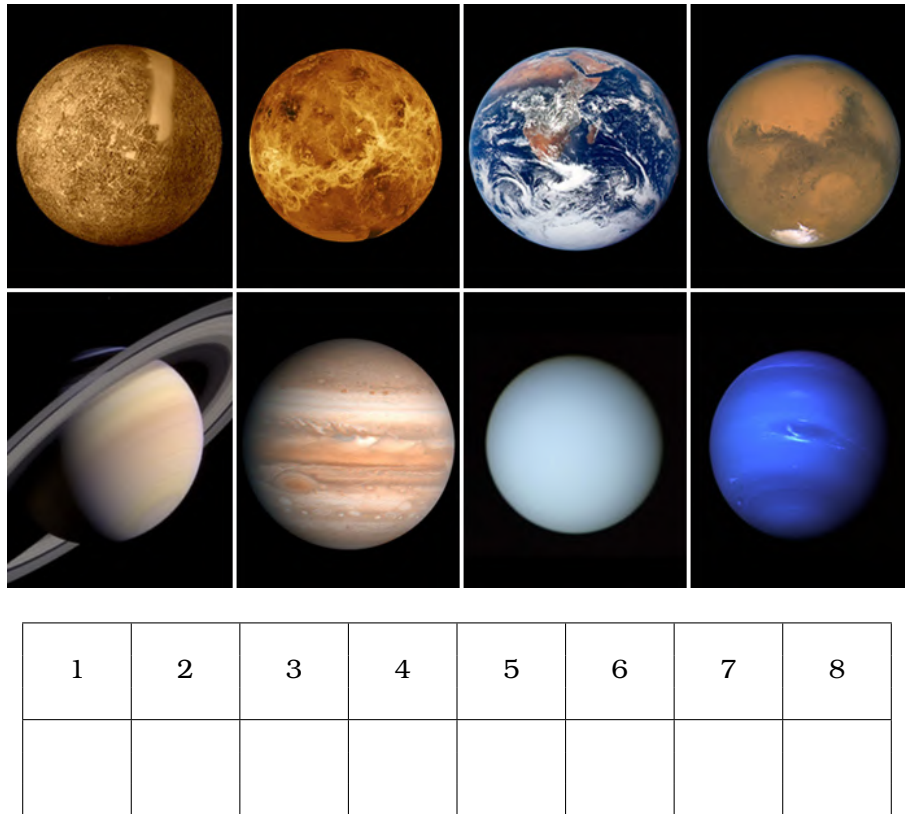


Figure 1: Diagram of the solar system for students to label in order of planetary distance from the Sun.

In addition to these convergent tasks with clearly defined answers, the differentiated homework included more open-ended and creative options for students to explore astronomical concepts. One assignment invited students to develop an illustrated children's storybook introducing a topic of their choice, such as the life cycle of stars, the history of space exploration, or the search for exoplanets. This project allowed students to delve deeply into an area of interest, synthesize their knowledge into an engaging narrative, and practice science communication skills by translating complex ideas into language appropriate for a young audience. Students with artistic talents could enhance their stories with original drawings, paintings, or digital images, while those with strong verbal skills could focus on crafting imaginative plotlines and memorable characters.

Another imaginative homework task had students create a travel brochure for a destination in the solar system, such as Mars, Europa, or Titan. Students conducted research on the physical characteristics, potential hazards, and scientific allure of their chosen world, then designed an attractive brochure persuading tourists to visit. This assignment encouraged students to view astronomy through an interdisciplinary lens, connecting scientific facts with creative expression and real-world applications. By developing a unique angle for their brochure and supporting it with relevant details, students could demonstrate both their mastery of the content and their ability

to communicate it compellingly to a lay audience. The open-ended nature of the task accommodated diverse student strengths and interests, from graphic design to persuasive writing to speculative thinking about the future of space travel.

For students who preferred more analytical challenges, the homework included quantitative problems and dataset investigations. One task provided light curve graphs from a recent supernova and asked students to estimate the peak absolute magnitude, duration, and total energy output of the stellar explosion. This assignment required students to apply their understanding of logarithmic magnitude scales, decay rates, and the inverse square law to extract meaning from authentic scientific data. Another homework option involved using online databases to compare the chemical compositions of Earth, Mars, and Venus, then developing an argument for which planet had the most potential to support life. Students had to sift through real planetary science data, identify relevant variables and trends, and construct evidence-based explanations for their conclusions. Such tasks mirrored the actual work of astronomers and provided opportunities for students to develop data literacy, quantitative reasoning, and argumentation skills in an astronomical context.

To help students connect classroom concepts to real-world observations, the homework frequently incorporated assignments leveraging astronomical software and mobile apps. In a project on lunar phases, students used a moon tracker app to log the Moon's appearance, position, and rise/set times over the course of a month. They then analyzed their observational data to identify patterns, calculate the period of the lunar cycle, and create a model explaining the relative geometry of the Earth, Moon, and Sun that gives rise to the phases. This extended assignment encouraged consistent engagement with the night sky and provided a concrete example of how motions in the Earth-Moon-Sun system produce observable effects. Another software-based homework task had students use the open-source planetarium program Stellarium to plan a stargazing session for a specific date, time, and location of their choosing. Students explored the simulated sky to identify prominent constellations, planets, and deep-sky objects visible that night, then researched the astronomical and mythological history behind those features to craft engaging stories for their imagined stargazing audience. This task integrated interactive technology with creative storytelling to build students' familiarity with the night sky and the cultural significance of celestial objects.

Field trips and service projects comprised some of the most immersive and memorable homework options. At a local observatory open house, students operated research-grade telescopes to view planets, nebulae, galaxies, and star clusters, then shared their knowledge and enthusiasm with visitors as informal docents. This experience provided hands-on training with authentic astronomical equipment, empowered students as science communicators, and strengthened their identities as members of a broader community of amateur and professional astronomers. For a citizen science project, students contributed to a crowdsourced search for interstellar dust impacts on the aluminum foils from the Stardust space probe. After completing an online training module, students analyzed hundreds of microscope images to identify craters produced by high-speed collisions with cosmic dust particles. Those who made significant discoveries had the opportunity to co-author scientific papers reporting the results. Participating in a genuine research effort showed students that anyone can contribute to the progress of astronomy and that our knowledge of the universe grows through collaboration between scientists and the public.

The mixture of individual, small group, and whole-class assignments accommodated students' varied social interaction preferences. Introverted students who preferred to process ideas independently could choose solo tasks like writing a poem about an astronomical object, developing a set of flashcards illustrating the HR diagram, or using

an online simulator to model the effects of gravitational lensing. Extroverted students who desired social engagement could opt for group projects such as co-authoring a script for a podcast about the accelerating universe, designing an astronomy-themed board game, or organizing a school-wide astronomy fair with booths and activities to teach younger students about the wonders of the cosmos. Collaborative work fostered a supportive classroom culture where students could learn from and inspire each other. At the same time, the option for individual projects ensured that solitude-seeking students had opportunities to think deeply and recharge.

By giving learners control over the format and focus of their homework, the differentiated approach aimed to stimulate intrinsic motivation and promote a growth mindset. Students could choose assignments that played to their strengths, whether that was analytical problem-solving, visual communication, creative expression, or public outreach. At the same time, the wide range of options encouraged them to push beyond their comfort zone and develop new skills. Qualitative evidence from student interviews and teacher observations suggested that the variety, flexibility, and relevance of the tasks increased many students' enthusiasm for astronomy and their persistence in the face of challenge. As one student reported, "I used to dread astronomy homework because it was tedious and repetitive. With the [differentiated] assignments, I actually looked forward to homework for the first time because I could explore topics that fascinated me and use my imagination. I put more effort into assignments because they were meaningful to me". A teacher noted, "I overheard one student say that he never thought he could be good at science until he got to write a screenplay about the Big Bang. Letting kids shine in diverse ways and bring their outside-of-school passions into the classroom was so powerful".

Quantitative measures of homework completion and quality also reflected positively on the differentiated approach. Over the semester, the mean on-time submission rate was 94%, up from 73% the previous year with uniform assignments. The average assignment grade was 91%, an increase from 81% before the intervention. While not conclusive due to potential confounding variables, these improvements suggest that giving students more agency in their homework had a beneficial impact on their academic engagement and performance.

Certainly, implementing differentiated homework on this scale required additional effort from teachers to develop multiple assignment options, monitor student progress, and evaluate varied products. Instructors needed to invest time upfront to design tasks that aligned with standards, incorporated appropriate supports and extensions, and could feasibly be completed within students' diverse home environments. Providing ongoing feedback to scaffold students' self-directed learning was also time-intensive. However, the teachers in this study felt that the benefits to student motivation, ownership, and outcomes made the approach worthwhile. As astronomy educator N. V. reflected, "When I saw my students' enthusiasm for homework skyrocket and their depth of understanding increase, I knew that I could never go back to a one-size-fits-all model. The differentiation pushed me to be more creative and responsive in my teaching, and that made me a better educator". With appropriate professional development and administrative support, differentiated astronomy homework seems to be a promising strategy for meeting the diverse needs of 21st century learners.

5. Discussion

The results of this study suggest that a differentiated, student-centered approach to astronomy homework can have positive impacts on high school students' engagement and learning. By providing choices, integrating authentic practices and technology, and accommodating student differences, the homework became more relevant

and meaningful. Students invested greater effort, produced high-quality work, and demonstrated improved achievement compared to traditional assignments.

These findings align with previous research on the benefits of differentiated instruction [3, 23], active learning [10, 12], and educational technology [5, 20, 24] in science education. Giving students agency and tailoring assignments to their needs can boost motivation and persistence [6]. Engaging students in scientific practices develops transferable skills and deepens conceptual understanding [8]. Technology provides access to real-world data and tools that make astronomy more authentic and collaborative [32].

However, this study also highlights challenges in implementing differentiated homework effectively and equitably. Designing high-quality tasks and managing increased student variability requires significant time, creativity, and flexibility from teachers [23]. Students may struggle if expectations are unclear or if they lack self-regulation skills [6]. Ensuring all students have access to necessary resources and support is an ongoing concern [26].

These challenges underscore the need for professional development and support for teachers to enact differentiated, reform-based practices in astronomy [11]. Teachers need training in designing tasks, facilitating student-centered learning, assessing diverse products, and integrating technology. Providing exemplars, rubrics, and time for collaboration can make the process more manageable. Partnering with astronomy researchers and informal educators can provide access to authentic data and experiences [2].

Schools also play a key role in enabling differentiated instruction. Ensuring equitable access to technology, materials, and lab space is critical. Building time for collaboration and individualized support into teachers' schedules can ease the workload. Aligning curriculum, instruction, and assessments around meaningful astronomy standards rather than isolated facts would provide a better foundation for student-centered learning [11].

The results also highlight the importance of student voice and experience in astronomy education research. While grades and test scores are important metrics, they do not fully capture the richness of students' learning and growth. Surveys, interviews, and student work samples revealed nuanced insights into how different learners engaged with and benefited from the differentiated homework. Involving students as co-designers and evaluators of instructional approaches can make astronomy education more responsive to their needs and interests [5].

6. Conclusion

High school astronomy education plays a crucial role in fostering scientific literacy, sparking curiosity about the universe, and preparing students for future STEM pursuits. Yet traditional instruction often fails to engage students or meet their diverse needs, leading to persistent achievement gaps and declining interest. Reimagining astronomy homework is one powerful lever for change.

This study demonstrates the promise of a differentiated, student-centered approach to astronomy homework. By providing choice, integrating authentic practices and technology, and accommodating learner differences, the homework became more meaningful and motivating. Students showed greater effort, produced higher-quality work, and achieved at higher levels than with traditional assignments. At the same time, the study reveals challenges in designing and managing differentiated tasks, supporting all learners, and changing entrenched practices.

To realize the full potential of differentiated astronomy instruction, teachers need substantive training, resources, and support. Schools must prioritize equitable access

to high-quality STEM experiences both in and out of the classroom. Sustained collaboration among educators, researchers, and policy makers is essential to align curriculum, instruction, and assessment around authentic astronomy practices and adapt to a rapidly changing field.

Involving students as partners and focusing on their lived experiences can ensure astronomy education meets their needs and aspirations. By taking a holistic, context-sensitive approach to studying and designing instructional innovations, researchers can generate knowledge that translates into meaningful change.

Astronomy has the power to inspire wonder, critical thinking, and a sense of connection to the larger universe. Ensuring all students have access to empowering, equitable astronomy learning experiences is both an educational and moral imperative. While the path forward is complex, this study offers one small guiding star. With creativity, commitment, and care, we can chart a course towards more inclusive and impactful astronomy education for all.

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