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ASTRONOMY EDUCATION PRACTICE TALK

Non-digital educational games to support conceptual change in astronomy education

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Abstract

Research on astronomy education has primarily focused on investigating students' conceptual understanding through the lens of student cognition. However, learning involves more than just acquiring or reorganising ideas. Despite this, there have been very few studies that have examined the learning process through multiple perspectives within a naturalistic environment. Additionally, the lack of validated astronomy game resources aligned with curriculum learning outcomes has hindered the inclusion of Game-Based Learning (GBL) in astronomy education. To address this issue, this paper explores the use of non-digital games as a pedagogical approach to support multidimensional conceptual change in post-primary astronomy education. Two dimensions of learning were examined: affective and cognitive. A mixed-methods quasi-experimental research approach was employed on a cohort of 474 post-primary students, divided into intervention and control groups. The results demonstrate robust evidence of the efficacy of non-digital games in promoting sustained conceptual change for post-primary students. The sociocultural environment created by the games was observed to favour student motivation and prolonged cognitive conceptual change. The GBL pedagogical intervention created multiple opportunities for students to review and refine their knowledge and perception of astronomy.

Keywords: Astronomy Education, Game-based Learning, Conceptual Change

1 Introduction

Astronomy, often described as the science of the universe, holds an enduring fascination for both scholars and laypeople alike (Lelliott and Rollnick, 2010). Research in astronomy education has consistently focused on unravelling the complexities of the universe for learners at all levels (Chastenay, 2018). Central to this endeavour is also the pursuit of effective pedagogical approaches that nurture students' comprehension of astronomical concepts and their appreciation of the cosmos (Cardinot et al., 2022). However, while this focus on assessing students' grasp of astronomical concepts has yielded valuable insights, it represents just one facet of the multifaceted process of learning. It should be noted that learning is not merely a cerebral exercise confined to the acquisition or rearrangement of ideas, rather it encompasses a multitude of experiences and factors (Deci and Ryan, 2012). Although there is a growing body of research investigating the learning process through various lenses, rela-

Table 1. Participants breakdown by gender in pre and post surveys.

	Intervention group		Control group	
	Pre-survey (N=254)	Post survey (N=253)	Pre-survey (N=210)	Post survey (N=221)
Female	63.4%	64.0%	42.9%	40.3%
Male	36.2%	34.8%	55.7%	52.0%
Prefer not to say	0.4%	1.2%	1.4%%	7.7%

tively few have ventured to explore the intricacies of the learning process from multiple perspectives (such as cognitive and affective learning) within formal educational settings. Furthermore, the integration of GBL in astronomy formal education has been hindered by a dearth of validated game resources aligned with science curriculum learning outcomes (Gee, 2014; Cardinot and Fairfield, 2019).

In this study, non-digital games are employed as the pedagogical intervention to promote conceptual change in astronomy formal education. Non-digital games, such as board and card games, have been shown to provide a unique opportunity to create a dynamic and engaging learning environment that fosters conceptual change while considering the affective dimensions of learning. In addition, it offers students a hands-on, interactive experience that encourages active participation, problem-solving, and collaborative learning.

Thus, this study seeks to bridge the research-practice gap by examining the potential of non-digital games as a pedagogical tool for supporting multidimensional conceptual change in post-primary astronomy education. It aims to provide insights into the efficacy of non-digital games in fostering conceptual understanding while considering the affective aspects of learning. By doing so, it contributes to a more comprehensive understanding of the learning process and offers practical guidance for educators and curriculum designers in the field of astronomy education.

2 Methodology

To investigate the potential of non-digital games in astronomy education, a mixed-methods quasi-experimental research approach was employed (non-equivalent groups and pre-,post-test design). The quasi-experimental design was chosen due to ethical limitations of randomly assigning students to the intervention and control groups. A cohort of 474 post-primary students (comprising Year 1, Year 2 and Year 3 of Junior Cycle in Ireland) were divided into intervention (N=258) and control groups (N=221), as described in Table 1, yielding a 98.7% and 88.2% response rate respectively.

During a six-week period, interventions were implemented within formal education settings in Irish schools. Each session had a duration of approximately one hour, aligning with the mean average duration of a typical Irish science class among the schools participating in the study. Treatment sessions comprised a concise discussion on the astronomy content featured in the game, followed by engaging in an astronomy-themed board game. Subsequently, a follow-up activity was conducted to reinforce both the game experience and the scientific concepts discussed. The control group sessions followed a parallel structure, albeit without incorporating any board games into the sessions.

2.1 Data collection tools

Data was collect during the first and last week to the implementation. Quantitative data were obtained from two instruments: a Knowledge Diagnostic Test and an Affective Learning Survey from both control and treatment groups. The diagnostic test was previously validated (cronbach's α = .72), consisting of a questionnaire with 26 open-ended and multiple choice questions published in Cardinot et al. (2021) related to the astronomy content involved in the board games, i.e. Earth-Sun-Moon model, seasons, gravity and the Big Bang. The questionnaire was designed to evoke students' thinking about astronomy, such as common alternative ideas that acted as distractors to investigate students' hybrid understanding about astronomy. It should be noted that these topics were selected after discussion with science teachers of the topics of the Junior Cycle science curriculum that are most challenging to teach. The Affective Learning Survey was developed to evaluate students' affective learning variables included in this study: attitudes and motivation towards astronomy. It included questions related to the affective constructs under investigation: motivation (enjoyment and motivation) and attitudes (self-efficacy and task value of astronomy). The questionnaire was adapted from previous literature to the context of this study. All scale items were rated on a five-point Likert scale from '1 completely disagree' to '5 completely agree' (Cohen et al., 2011).

3 Results

The results of this study provide compelling evidence of the efficacy of non-digital games in promoting sustained conceptual change among post-primary students in astronomy education. The sociocultural environment fostered by these games proved instrumental in enhancing student motivation and facilitating multidimensional conceptual change.

3.1 Cognitive Dimension

One of the primary outcomes of this study was the substantial improvement in students' cognitive understanding of astronomical concepts in the intervention group compared to the control group. The knowledge diagnostic tests administered before and after the intervention revealed a marked increase in scores among students who engaged with non-digital games as shown in Table 2, suggesting that the non-digital games effectively facilitated cognitive conceptual change.

The structured gameplay and interactive nature of the games provided students with opportunities to apply their knowledge in context. This hands-on learning approach allowed students to reinforce their understanding of astronomical concepts by actively engaging with them in a meaningful way. As a result, students in the intervention group exhibited a deeper and more nuanced grasp of the subject matter.

Beyond mere retention of facts, the use of non-digital games encouraged active engagement with astronomical concepts. Students were required to make decisions, solve problems, and collaborate with peers during gameplay. This active participation not only solidified their knowledge but also enhanced their critical thinking and problem-solving skills, which are essential components of cognitive learning.

3.2 Affective Dimension

The study also explored the affective dimensions of learning, including students' attitudes and motivation. The affective learning surveys administered before and after the intervention indicated a notable shift in students' attitudes towards astronomy

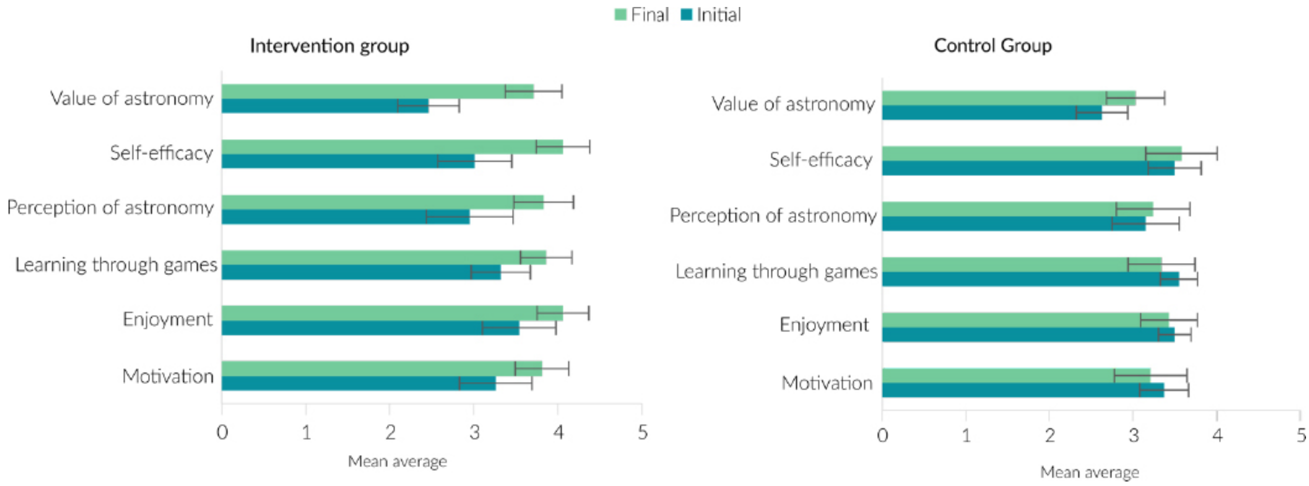

Figure 1. Participants' pre and post means and standard deviations for each affective domain component by group. An increase was observed in all cases, but the magnitude of the increase was greater and statistically significant only for the treatment group at $p < .001$

in the intervention group (see Figure 1). Students reported increased interest, enthusiasm, and curiosity for the subject matter after engaging with non-digital games. This suggests that the games successfully influenced students' affective responses to astronomy.

The collaborative nature of the games, combined with a sense of competition, contributed to positive affective outcomes. Students found the games enjoyable and engaging, which positively impacted their motivation to learn astronomy. The games created a motivating learning environment that encouraged students to actively participate and invest in their learning journey.

Moreover, the study also delved deeper into the affective dimensions through focus groups and classroom observations. Students who participated in the focus groups expressed a strong sense of satisfaction and enjoyment when playing the non-digital games. They appreciated the hands-on experience and the opportunity to interact with peers. Classroom observations during game sessions further confirmed these qualitative insights, illustrating a lively and participatory learning environment characterised by enthusiasm and intrinsic motivation.

4 Conclusion

The incorporation of non-digital games created a dynamic and engaging learning environment that fosters conceptual change. The positive effects observed in student motivation and attitudes towards astronomy highlight the importance of considering affective aspects in educational research. Moreover, the results align with previous research in which the role of social interaction and context are key to the learning process. Non-digital games inherently promote social interaction, collaboration, and peer-to-peer learning. These aspects contribute to the creation of a sociocultural environment that supports student motivation and cognitive conceptual change.

Thus, the implications of this study extend to both theory and practice in astronomy education. Educators can benefit from incorporating non-digital games into their teaching strategies, recognising their potential to promote sustained conceptual change while enhancing student motivation and engagement. Moreover, curriculum designers should consider the affective dimensions of learning when designing astronomy courses, acknowledging the role of student attitudes and emotions in the learning process.

5 Acknowledgment

We would like to thank all researchers, students and teachers who kindly participated in this work.

6 Conflict of Interest

No potential conflict of interest was reported by the authors.

7 Ethical Statement

Ethical approval to conduct this study was obtained from the University of Galway (Ref. 17-May-04), and the necessary additional permissions were obtained from the schools in which this study was conducted. The study participants provided written informed consent before enrollment into the study.

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Table 2. Summary of pre- and post-test results. Although both groups showed changes in the pre and post-test means, the results were larger and statistically significant only for the intervention group.

	Intervention				Control				t-test (p) Intervention vs. Control	
	Pre-test M (SD)	Post-test M (SD)	t-test (p) pre vs. post	Cohen's d	Pre-test M (SD)	Post-test M (SD)	t-test (p) pre vs. post	Cohen's d	Differences between pre and post tests	Cohen's d
Year 1	24.5 (6.2)	44.0 (19.6)	-8.8 (<.0001)	.92	23.5 (8.6)	23.9 (14.5)	-.16 (.875)	.02	6.1 (.0001)	.98
Year 2	27.7 (6.4)	55.5 (21.5)	10.5 (<.0001)	1.20	23.8 (7.2)	26.5 (15.2)	-1.4 (.175)	.06	7.6 (.0001)	1.24
Year 3	26.6 (11.7)	32.9 (15.9)	-2.9 (.008)	.31	22.9 (5.2)	22.6 (6.1)	.33 (.743)	.08	2.7 (.009)	.42

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