IMPACT OF CURIOSITY IN LEARNING: A SYSTEMATIC LITERATURE REVIEW

Rizki Novendra [1]*, Wakhinuddin [2], Dedy Irfan [3], Adolf Bastian [4], Yogi Yunefri [5], and Nurliana Nasution [6]

[1,4,5,6] Faculty of Computer Science, Universitas Lancang Kuning, Indonesia.
[1,2,3] Faculty of Engineering, Universitas Negeri Padang, Indonesia.
Email: [1]rizkinovendra@unilak.ac.id (*Corresponding Author), [2] wakhinuddin@ft.unp.ac.id, [3]irfankumango@gmail.com, [4]adolf@unilak.ac.id, [5]yogiyunefri@unilak.ac.id, [6]nurliananst@unilak.ac.id

DOI: 10.5281/zenodo.11616356

Abstract

This research provides a discussion or empirical study on the impact of curiosity in learning. The purpose of this study is to provide knowledge regarding the importance of curiosity in learning as well as directions for future research. This study uses the prism framework method to identify relevant studies. There were 68 out of 416 articles from the Scopus database that met the criteria between 2019-2023. The findings show that curiosity contributes significantly to learning outcomes by increasing motivation, questioning skills, and depth of understanding. It was identified that exploration strategy is an effective strategy to trigger curiosity in the learning process.

Keywords: Project Based Learning, Curiosity, Object Oriented Analysis and Design.

I. INTRODUCTION

Learning is a complex process that is influenced by a variety of contextual factors. These factors include learner diversity, digital media, location, knowledge domain, sequence of events, activity, historical period, social relationships, and significance horizon. [1]. The context in which learning takes place can have a significant impact on the transfer of knowledge and skills [2]. Teachers need to be aware of the social, political, economic, and legal context in which they operate, as it affects their work in the classroom [3]. Understanding the general context of learning is important for educators to effectively plan and deliver lessons that meet the needs and aspirations of their learners [4]. By considering these contextual factors, educators can create learning environments that support and enhance the learning process.

Further understanding of the factors that influence learning, including elements such as curiosity [5] [6] [7]. Curiosity has been shown to enhance learning by acting as a reinforcer of reward-related feedback processing. It is considered a metacognitive feeling that is triggered by evaluating one's information needs and predicting the likelihood of obtaining significant information.

Curiosity can be aroused not only through individual activities but also through interpersonal activities, with the latter having a stronger influence. Understanding the social dynamics in collaborative learning and identifying the subtle social scaffolding of curiosity can help elicit and sustain curiosity in technology-enhanced learning environments.

Several studies have explored the relationship between curiosity and learning outcomes. Wade and Kidd found that curiosity is best predicted by learners estimates of their current knowledge, while learning is predicted by curiosity and objective measures of knowledge. [8]. Eschmann et al. showed that the trait of curiosity is stable over time and positively related to the frequency of real-life information-seeking behaviour [9]. Feraco et al. identified adaptability, curiosity, and perseverance as key soft skills that positively influence academic achievement and life satisfaction (10). [10]. Spitzer and Kiesel replicated previous findings that curiosity follows an inverted U-shaped function of trust, with curiosity highest at moderate levels of trust in knowing information. [11]. These findings highlight the importance of curiosity in learning and show that it is influenced by various factors, including knowledge estimates and individual traits.

Curiosity plays an important role in learning. The impact of curiosity in the context of learning is not fully understood. While some research suggests that curiosity can enhance learning [12], others argue that the mechanisms that drive curiosity and learning outcomes are not identical [11].

Understanding how curiosity affects learning is critical to development [9]. Curiosity is associated with increased neural dynamics in mesolimbic dopaminergic circuits, which are involved in information seeking [13]. However, it is not yet clear whether curiosity and its associated neural dynamics drive information seeking in real-life situations [14].

Moreover, exploration and curiosity are critical components of successful reinforcement learning, but optimal approaches are computationally challenging. Further research is needed to fully understand the role of curiosity in learning and to develop effective strategies to incorporate curiosity into the learning environment. This research addresses a systematic review of the impact of curiosity in the learning process. Specifically, this study uses the following two research questions.

1) Rq1: How does curiosity affect learning motivation?
2) Rq2: How Effective Strategies to Spark Curiosity into the Learning Environment

II. LITERATURE REVIEW

Curiosity plays an important role in learning by encouraging information-seeking behaviour and enhancing successful retrieval of memories [15]. Metacognitive abilities such as self-confidence and prior knowledge estimates are linked to curiosity, influencing learning outcomes [16]. In the context of online learning, curiosity and motivation to learn positively impact self-directed learning, with motivation being a stronger predictor [17].

Curiosity not only influences feedback processing but also improves memory retention, demonstrating its importance in the learning process [18]. Active curiosity-driven learning, where individuals generate questions to search for missing information, leads to increased curiosity, information seeking and better memory retention [19]. Overall, curiosity encourages individuals to search for knowledge gaps, formulate questions, and actively engage in the learning process, ultimately improving learning outcomes

To implement curiosity in learning, one can utilize intrinsic motivation methods that add intrinsic rewards to the learning process. encouraging exploration and expanding the sample space [20]. In addition, combining variables such as triggering emotions through scientific activities, relevance of information, and beliefs about the malleability of interests in the classroom can increase student motivation through curiosity [21]. Learning environment, the use of project-based learning models can also be done in the process of applying curiosity in learning [22]

www.commprac.com
ISSN 1462 2815

III. MATERIALS AND METHODS

a) Review Approach

The systematic literature review research using PRISMA involved several stages. First, a literature search was conducted to identify relevant studies [23]. This involves systematically searching for studies and transparently reporting the search methods and sources of information [24]. Subsequently, the identified studies were screened and selected based on predefined inclusion criteria [25].

After selecting the studies, data extraction was performed, where relevant information from the selected studies was extracted and recorded. [26]. A quality analysis of the included studies can also be performed [27]. Finally, the findings of the selected studies are synthesized and reported in a systematic review. The PRISMA guidelines provide a framework for reporting the various stages of the systematic literature review process, ensuring transparency and reproducibility.

b) Identification and Screening

In this study, the Scopus database was used to search for data to be collected and analysed. The Scopus database has been widely used in bibliometric research due to the comprehensive nature of its bibliographic data in relation to time span. Several papers in the abstracts provided mention the use of the Scopus database to conduct bibliometric analysis.

For example, one paper on derivatives markets used the Scopus database to collect data [28]. Articles were searched by time span from 2019 to 2023 using the keywords curiosity in learning, impact of curiosity in learning and curiosity and learning.

As previously stated, the articles used are based on a time span ranging from 2019 to 2023. All articles are in English from the Scopus database. Based on the search for articles on the Scopus database there are 416 articles.

Based on this data, 67 duplicates were identified, 349 studies were screened for readability based on their abstracts. A total of 227 studies were excluded due to wrong study design because the discussion of curiosity was not in the realm of education. The number of articles in this study that were reviewed was 68 articles. See figure 1 prisma flowchart3

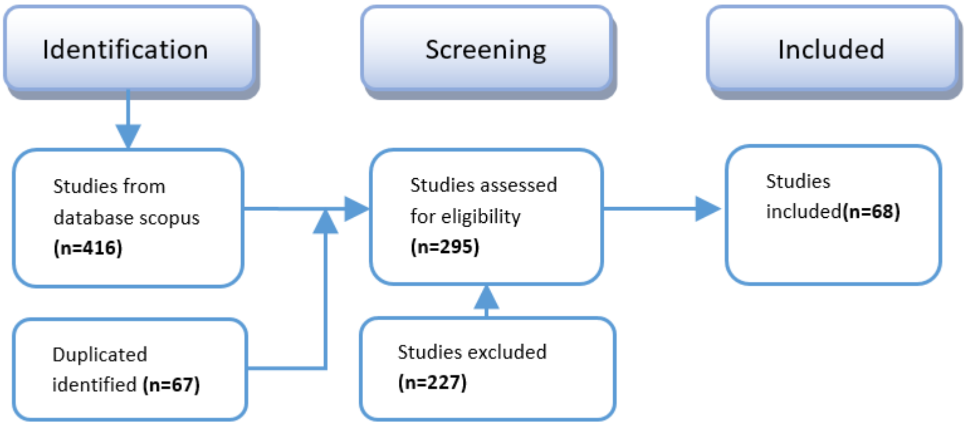

Fig 1: Prisma flowchart

IV. RESULT AND DISCUSSION

A. Articles summary

A search was conducted on the Scopus information source, resulting in 416 journal articles that were successfully identified using a combination of Title-Keyword searches, namely "Curiosity and Learning" AND "Curiosity in Learning" OR "Impact Curiosity in Learning". After going through the process of applying inclusion criteria, duplication elimination, it was found that there were 349 eligible articles. An additional manual screening process, involving evaluation of titles and abstracts, resulted in 68 articles being deemed relevant. Subsequently, these articles were re-evaluated to determine their relevance in responding to the research question, and a total of 68 articles continued to meet the criteria. Information regarding the 68 articles by year of publication can be seen in Figure 2.

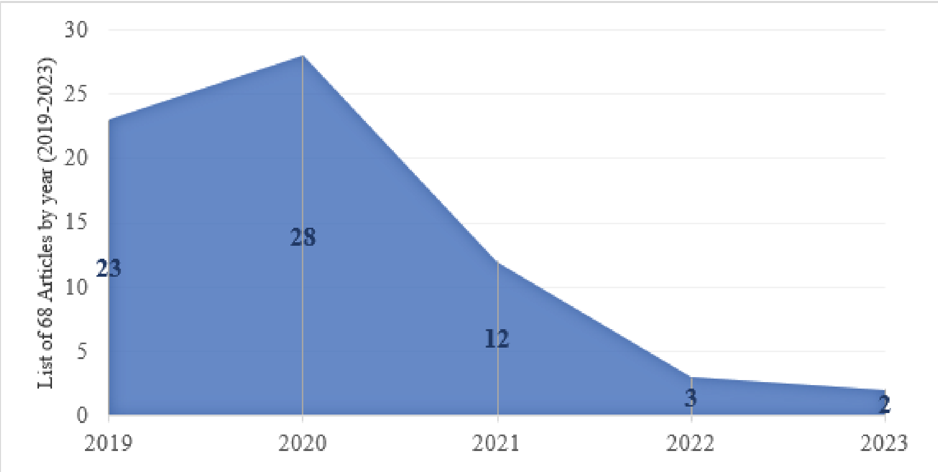

Fig 2: 68 Articles by year

List articles that support the Research Question:

Table 1: Research question and articles

No.	Research Question	Article
1	How does Curiosity Affect Motivation to Learn?	(21-80)
2	What are some effective strategies to bring curiosity into the learning environment?	[29]–[36], [38]–[50], [53], [55], [58]–[61], [64], [65], [67]–[72], [74]–[87], [89]–[108]

B. How does curiosity affect learning motivation?

Curiosity has a significant impact on motivation to learn. It is described as the need for knowledge or information and the motivation to pursue it through exploration. Curiosity differs from interest, as it is driven by the goal of seeking resolution or filling a specific knowledge gap. When individuals are curious, they are motivated to actively engage in learning and seek answers through their own efforts. Curiosity enhances memory formation and can lead to improved learning outcomes. It activates the hippocampus and related brain regions involved in learning and memory. In addition, curiosity is associated with positive affect and resolution of perceived ignorance. The desire for agency and control over one's learning process is a key aspect of curiosity. Understanding and fostering curiosity can be beneficial in educational practice, as it increases motivation and enjoyment in learning. In the context of learning motivation below describes learning motivation by curiosity:

1) The Importance of Curiosity in Learning

a) Essential Drivers of Learning

Curiosity is an important factor in the learning process. Learners with high curiosity tend to seek explanations for the things they observe. This curiosity, called explanation-seeking curiosity (ESC), is triggered by a variety of factors, such as novelty or surprise, reactions from adults who are perceived to be knowledgeable, or expectations of future information gains. Satisfaction of this curiosity is usually achieved through causal interventions or by asking questions. This curiosity is very important in children's learning because it combines active learning and intrinsic motivation with the value of explanatory content, which can reveal the causal and invisible structures of the world to support generalizable knowledge. Curiosity is an important driver in learning as it has several key roles in children's cognitive processes and development, as explained below:

Active Exploration Drivers: Learners with high curiosity tend to explore their environment more actively. They seek out new knowledge and experiences, which help them understand the world around them.

Intrinsic Motivation: Curiosity is a form of intrinsic motivation that drives children to learn without the need for external rewards. Learners learn because they want to satisfy their curiosity, not because of external encouragement or incentives.

Formation of Generalizable Knowledge: Through curiosity, learners seek explanations that help them understand the causal and invisible structures of the world. This allows them to build knowledge that is more abstract and can be applied in a variety of situations.

Enhanced Exploratory Learning: Curiosity encourages learners to not only learn about targeted information but also to continue exploring non-targeted information. This leads to broader and deeper learning.

Curiosity also has an important role in facilitating learning and is associated with greater retention, achievement and intelligence. Based on the research mentioned, uncertainty in instruction, when combined with the expectation of uncertainty, can increase curiosity and improve knowledge transfer to new contexts. This suggests that curiosity can predict knowledge transfer, and positive affect can predict learning.

In an educational context, uncertainty can trigger curiosity, which can then lead to improved learning and knowledge transfer. Research conducted showed that students who experienced uncertainty in learning tended to have higher transfer test scores compared to a group that did not have the expectation of uncertainty. Although there was no difference in task performance between the groups, curiosity was shown to be associated with greater learning and knowledge transfer.

Thus, curiosity generated through uncertainty in learning activities can facilitate the development of transferable knowledge. This demonstrates the importance of curiosity in supporting knowledge retention, academic achievement and intelligence enhancement, as curiosity encourages exploration and deeper understanding of the material learned.

b) Improving Learning Outcomes

Curiosity is an important factor in the learning process as it can motivate individuals to explore and acquire new knowledge. Here are some ways in which curiosity can improve learning outcomes:

Increased Motivation: Strong curiosity can encourage students to learn with more enthusiasm. When students are interested in a topic, they tend to be more motivated to pursue a deeper understanding.

Development of Questioning Skills: Inquisitive students tend to ask more questions. This helps them to deepen their understanding and also develop critical thinking skills.

More Active Learning: Curiosity drives students to be active learners. They not only passively receive information, but also actively seek and explore new information.

Improved Retention: When students are interested in the material they are learning, they tend to be more focused and engaged, which can improve information retention.

Deeper Learning: Curiosity can drive students to not only learn basic facts, but also to understand underlying concepts and principles.

Development of Research Skills: Curiosity can encourage students to conduct independent research and exploration, which are essential skills in higher education and in the workplace.

Adaptation to New Learning: Inquisitive students are often more open to new ideas and different approaches to learning, which can help them adapt to changes and challenges in the learning process.

C. What are Effective Strategies for Sparking Curiosity into the Learning Environment

All articles have been analysed to answer research question 2. Based on 68 articles, several effective strategies to trigger curiosity in learning were found. There are 15 articles that state that exploration is an effective strategy to trigger curiosity in learning, followed by the strategy of giving rewards or prizes and so on. See figure 3

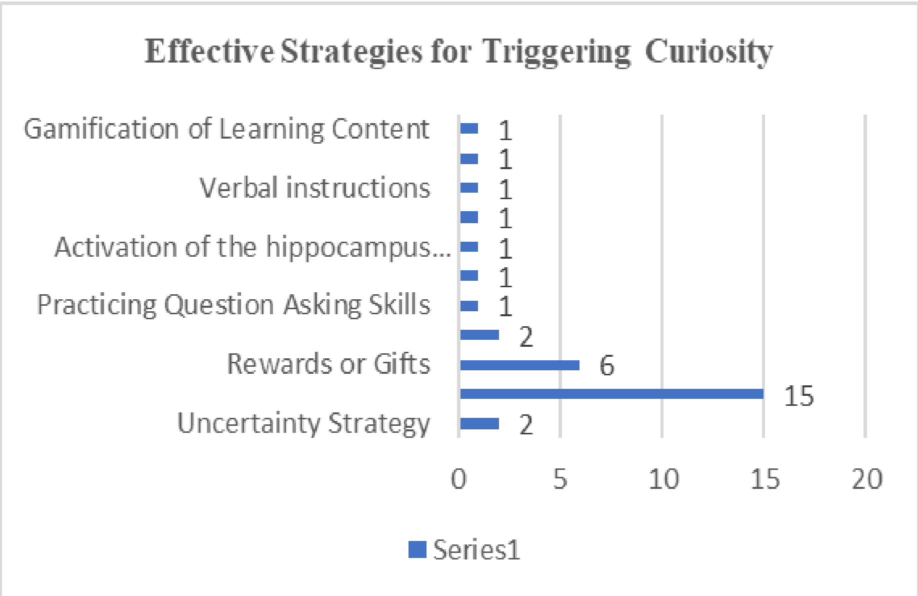

Fig 3: Effective Strategies Based on Articles

1) Exploration

In an educational context, exploration is a process in which students actively seek new knowledge and experiences through activities that encourage curiosity and inquiry. Exploration allows students to engage with learning materials in depth, develop better understanding and acquire critical skills through direct experience and interaction with their learning environment. Exploration in the classroom often involves student-cantered learning methods, such as project-based learning, experiments or field activities, where students are given the opportunity to ask questions, conduct investigations and find answers through their own discovery process. It also includes the development of scientific attitudes and process skills such as observing, classifying and hypothesizing, which are important parts of science literacy.

Exploration in education is also linked to improving students' science literacy competencies, which is the ability to understand and apply scientific concepts, think critically, and make evidence-based decisions. Therefore, exploration not only enriches students' learning experiences but also prepares them with the skills necessary for success in the 21st century.

Exploration has a close relationship with triggering curiosity. Curiosity is an intrinsic drive that encourages individuals to seek new knowledge and experiences. In an educational context, exploration through student-cantered learning activities can enhance their curiosity. Research shows that curiosity is positively related to motivation to explore as well as actual exploration behaviour. When students experience surprise or cognitive dissonance, it can trigger curiosity which in turn encourages them to explore further.

Curiosity, as one aspect of scientific attitude, plays an important role in science education. Curiosity encourages students to embrace new experiences and learn deeply. This is important because curiosity that is not optimally developed can lead to a lack of questioning and discussion activities in learning, which are important indicators of curiosity. Therefore, exploration in education aims to optimize students' curiosity, which in turn can improve science literacy competencies.

The exploration stage to spark curiosity involves several interrelated steps:

a) Introduction of New Stimulus or Unexpected Information

When students are confronted with information or phenomena that do not match their current understanding, this can lead to surprise or cognitive dissonance, which can trigger curiosity.

b) Questioning and Inquiry

The curiosity that has been triggered encourages students to ask questions and conduct further investigations. They start looking for answers and additional information to understand the stimulus or new information.

c) Exploration and Discovery

Students engage in active exploration, both physically and intellectually, to find answers or understand deeper concepts. This could be through activities such as experiments, research, or information seeking.

d) Deep Learning Experience

Through exploration, students gain in-depth learning experiences, which enable them to construct new understandings and integrate information into existing knowledge frameworks.

e) Maintenance of Curiosity

Ongoing exploration and positive learning experiences can nurture curiosity, encouraging students to continue seeking new knowledge and experiences. This creates a continuous cycle of learning where curiosity and exploration mutually reinforce each other

f) Reflection and Evaluation

Once students have engaged in exploratory activities, they are encouraged to reflect on their learning experience. This reflection can include questions such as what they have learned, how they felt about the learning process, and what challenges they faced during the exploration. Reflection helps students internalize new knowledge and understand how it connects to what they already know. Meanwhile, Evaluation is the process of assessing the results of exploration and learning. It can involve self-assessment or assessment by the teacher, aiming to determine the extent to which learning objectives have been achieved. Evaluation can include assessment of process skills and scientific attitudes that have been developed during exploration, as well as students' conceptual understanding.

2) Reward or Prize

The reward-learning framework explains the relationship between knowledge acquisition, curiosity, and interest by positing that the acquisition of knowledge itself serves as a reward, and the anticipation of this rewarding experience is what drives information-seeking behaviour. This framework suggests that when individuals recognize gaps in their knowledge, they are motivated to seek information because they expect to find the process of acquiring new knowledge rewarding.

Curiosity and interest, within this framework, are not considered as constituent elements of the knowledge-acquisition process itself. Instead, they are viewed as subjective constructs that people have developed to describe certain aspects of this process. The framework integrates insights from neuroscientific and psychological theories on curiosity and interest, such as the knowledge-gap theory, the four-phase model of interest development, the expectancy-value approach to interest, and the self-regulation of motivation model, to provide a comprehensive understanding of the psychological processes underlying curiosity and interest.

The reward-learning framework also emphasizes the importance of focusing on sustaining the knowledge-acquisition process rather than defining curiosity or interest themselves. It argues that once the precise neural and psychological processes that underpin knowledge acquisition are explained, it is no longer necessary to assume curiosity or interest in the psychological process. This approach aims to provide a common ground for interdisciplinary research and to encourage a more granular investigation of the knowledge-acquisition process and its long-term development.

Curiosity and impulsivity share a paradoxical relationship in that while curiosity is generally viewed as a positive trait that is critical to learning and is seen as a desirable quality, impulsivity is often considered maladaptive and associated with negative

ISSN 1462 2815

outcomes. Despite these differing societal perceptions, both curiosity and impulsivity exhibit remarkable overlaps in terms of their behavioural manifestations and underlying neural substrates.

Commonalities between curiosity and impulsivity include their reliance on similar neural circuits, particularly those involving frontostriatal pathways and dopaminergic inputs from the midbrain, which are critical to both reward processing and impulsive behaviour. These shared neural mechanisms suggest that the drive to seek information (curiosity) and the tendency to act on immediate desires (impulsivity) are closely linked in the brain.

In terms of decision-making and learning, the overlap between curiosity and impulsivity can be seen in how both can lead to an increased focus on immediate information acquisition. Curiosity can enhance learning by motivating individuals to seek out new information and by increasing attention and exploration, which can lead to better memory consolidation through dopaminergic modulation. However, when curiosity manifests impulsively, it may lead to a preference for immediate over delayed information, which can resemble impulsive decision-making.

The paradox arises because the same neural circuits that contribute to the beneficial aspects of curiosity can also underlie the less desirable aspects of impulsivity. For example, the anticipation of the reward of gaining new knowledge can drive both curiosity and impulsive behaviour, leading to a tension between the desire to explore and the need to control impulses for optimal decision-making.

This relationship has implications for educational and cultural practices. For example, efforts to dampen impulsivity in educational settings might inadvertently discourage curiosity if not carefully balanced, as both traits are intertwined and can influence the developmental trajectory of learning and decision-making. Understanding the commonalities between curiosity and impulsivity can help in designing interventions and environments that foster healthy curiosity while managing impulsivity, thereby enhancing learning outcomes.

3) Uncertainty Strategy

Uncertainty in instruction has been found to significantly affect students' curiosity and learning outcomes. According to the research, introducing uncertainty in academic settings, particularly in the form of Expected Uncertainty (EU) and Unexpected Uncertainty (UU), can lead to increased curiosity among students. This heightened curiosity is associated with improved learning and the transfer of knowledge to new contexts.

The study that explored the relationship between uncertainty, curiosity, learning, and transfer involved three conditions: No Uncertainty (NU), Expected Uncertainty (EU), and Unexpected Uncertainty (UU). It was conducted with middle school students learning about physics concepts. The findings suggest that when students are faced with uncertainty in instruction, it can provoke their curiosity, which in turn can lead to greater learning and the ability to apply knowledge in different situations.

Specifically, the study found that students in groups with expectations of uncertainty (EU) had higher transfer test scores compared to the group with no uncertainty expectations (NU). This indicates that uncertainty can facilitate the development of transferable knowledge. Curiosity was found to predict transfer, but the condition of uncertainty overshadowed the direct effect of curiosity on transfer. Positive affect was

ISSN 1462 2815

also found to positively predict learning outcomes, suggesting that the emotional response to uncertainty can influence the learning process.

Moreover, the study involved students working on Invention activities and completing questionnaires before and after watching instructional videos. The manipulation check confirmed that the uncertainty groups felt more uncertain than the control group, and they also reported higher levels of curiosity. However, there were no significant differences in learning from pretest to posttest across the groups, indicating that the impact of uncertainty on curiosity and transfer may not directly translate to immediate learning gains as measured by traditional tests.

The research highlights the value of incorporating uncertainty into science instruction and its potential impact on learners' curiosity and knowledge transfer. It suggests that inducing uncertainty in lessons can lead to motivated, curious learners who are better equipped to apply their knowledge in new and varied contexts. However, the study also identified limitations and suggested future research directions, such as exploring individual differences in intolerance of uncertainty and replicating the findings with more robust learning measures.

In summary, uncertainty in instruction can enhance students' curiosity, which is a critical factor in learning and the transfer of knowledge. The relationship between uncertainty and learning outcomes is complex and influenced by various factors, including students' affective responses and expectations of uncertainty.

4) Application of Learning Model

Problem-based learning with character emphasis (PBL-CE) has a significant effect on students' critical thinking skills and curiosity. It supports students in reaching higher categories of critical thinking skills and curiosity, making it an effective treatment for enhancing these aspects of students' development. PBL-CE is designed to integrate character-building activities within the learning process, which not only focuses on academic content but also on the development of students' character, including traits such as curiosity about environmental and social problems.

During PBL-CE, students are faced with authentic problems that are relevant to their environment, which encourages them to think critically about issues they encounter in their daily lives. The use of images and news from electronic media as part of the learning materials is particularly effective in helping students develop their thinking skills. By engaging with real-world problems, students are prompted to exercise and improve their critical thinking and to become more curious about the world around them.

Furthermore, the research indicates that naturalist intelligence does not have a significant effect on students' critical thinking skills and curiosity, and the interaction between PBL-CE and naturalist intelligence does not affect these skills either. This suggests that PBL-CE is equally effective for students with varying levels of naturalist intelligence.

5) Practicing Questioning Skills

To train questioning skills, especially curiosity-driven questions, previous research has explored specific practice designs. One method used is to provide semantic and linguistic clues to train children to ask more divergent questions. However, this method has limitations as it relies on manually generating such hints, which can be a lengthy and expensive process. In this context, advances in the field of natural language processing (NLP) can be leveraged to automate the production of pedagogical content. Recent research suggests using large language models (LLMs) such as GPT-3 to automate the generation of such prompts. The method used is "prompt-based", where tasks are described to the LLM in natural text, and the LLM then generates the desired content. The results show that the generated content is relevant and useful.

In addition, a field study involving elementary school children showed that training with the content generated by GPT-3 can help improve children's performance in asking divergent questions. This research makes an important contribution in the effort to utilize NLP in educational applications, particularly in curiosity training. Thus, training question-asking skills can be done by utilizing NLP technology to generate prompts that can facilitate the generation of divergent questions by children, which in turn can improve their learning process.

6) Spontaneous Interaction

The stages of the curiosity-inducing spontaneous interaction strategy involve several steps related to prior knowledge, surprise, and curiosity-induced exploration. The following are those stages:

a) Prior Knowledge Monitoring

This is the first step where individuals monitor their existing state of knowledge. When there is cognitive uncertainty or information gaps, curiosity is triggered. Individuals will feel curious when they encounter a situation where some alternative interpretation is compatible with the current situation, based on their prior beliefs.

b) Surprise Experience

Surprise plays an important role in triggering curiosity. When infants or individuals observe a surprising event that goes against their expectations, such as an object with unexpected properties, they tend to pay more attention to the object and learn better about the new properties of the object. Surprise can be seen as an attempt to test hypotheses about the surprising object and can trigger curiosity-based exploration.

c) Selective Exploration

After experiencing surprise, individuals tend to engage in selective exploration to seek explanations. This can involve trying to reproduce the startling event or seeking more information about the startling object or phenomenon.

7) Activation of Hippocampus and Parahippocampal Gyrus

Activation of the hippocampus and parahippocampal gyrus refers to the stimulation of brain regions involved in learning and memory. This activation becomes effective in triggering curiosity because curiosity naturally involves the learning process, which in turn relates to memory formation. Curiosity enhances memory formation for acquired information, and the hippocampus along with its associated parahippocampal gyrus, plays an important role in this process. Furthermore, variations in the involvement of the hippocampus can predict the accuracy of future recall of information. Increased activity while waiting for an answer to a highly intriguing question and after answering the question incorrectly may lead to more accurate recall. Therefore, activation of these regions supports curiosity-motivated learning, demonstrating the importance of the hippocampus and parahippocampal gyrus in triggering and maintaining curiosity.

To implement the activation of the hippocampus and parahippocampal gyrus in order to trigger curiosity, we can design tasks or activities that utilize learning and memory mechanisms. Here are some ways in which this can be implemented:

a) Use of Challenging Questions

Asking questions that are challenging and require critical thinking can stimulate the activity of the hippocampus and parahippocampal gyrus. Questions that arouse curiosity can increase engagement with the material and facilitate stronger memory formation.

b) Providing Partial Information

Providing partial information and letting individuals explore to find the full answer can trigger curiosity. This process utilizes the reward-learning mechanism associated with information seeking and learning.

c) Use of Games and Simulations

Games designed to trigger exploration and discovery can activate brain regions associated with curiosity. Games that require problem solving and active exploration can increase activation of the hippocampus and parahippocampal gyrus.

d) Project Based Learning

Project-based learning that allows students to explore a topic in depth and from multiple perspectives can trigger curiosity and activation of relevant brain regions.

e) Use of Narratives or Stories

Interesting and imaginative stories can increase curiosity and trigger activation of the hippocampus and parahippocampal gyrus. Narratives that require creative and imaginative thinking can strengthen learning and memory.

By implementing these strategies, it is possible to design learning experiences that not only spark curiosity but also maximize the activation of the hippocampus and parahippocampal gyrus, which are essential for effective learning and memory formation.

8) Intervention Method

Intervention methods can trigger curiosity in different ways. First, in accordance with complexity-based theories such as the information gap hypothesis, the proposed model suggests that we can influence people's curiosity by inducing information gaps. Second, the results suggest that if we want to make people curious about tasks or activities that are new and for which they lack confidence, subtle changes in the structure of the environment may be a step towards achieving this. This could include creating an environment where the past is independent of the future.

Third, this work shows that people's curiosity can be driven towards harder-to-learn tasks if they perceive the task as useful or important. When people perceive an event or task as important, they will expect the task to have a higher probability of occurrence, thus causing greater curiosity for the task. For example, a student who wants to learn to solve calculus problems will be more curious about solving such problems if he wants to pursue math in the future or feels that he can relate this knowledge to other domains. In addition, future research is important to develop intervention methods to stimulate curiosity in various educational and learning settings. The current research is building on the framework outlined for developing such intervention methods. Overall, this approach emphasizes that curiosity is not fixed but can be modified, and various ways have been suggested to stimulate people's curiosity.

9) Verbal instructions

Verbal instruction can spark curiosity by increasing efficiency and effectiveness in learning, especially when teaching actions whose functions are not obvious and require imitation to acquire. When verbal instruction is added to the learning process, such as in stone tool making, the process becomes much more efficient. This suggests that effective teaching, which often relies on language in instruction, can promote curiosity by providing a deeper understanding of the action being taught and its context, thus fuelling the desire to explore and experiment further.

Moreover, learning processes involving verbal instruction can facilitate innovation and unintentional mistakes, which often lead to the improvement of existing techniques. Thus, verbal instruction not only enriches an individual's knowledge but can also trigger curiosity and a drive for innovation.

10) Making Predictions

Asking learners to generate predictions is an efficient instructional strategy that involves several stages designed to promote curiosity and learning. Below are the stages involved in this process, with references to relevant literature:

a) Increased Arousal and Attention

Generating predictions can increase learners' arousal and attention to the material to be learned, making the upcoming information feel more relevant and interesting.

b) Anticipation of Solutions

Learners anticipate the correct solution or answer, which increases their attention to existing knowledge gaps..

c) Promotion of Surprise and Curiosity

This strategy promotes surprise and curiosity, both of which can increase motivation and engagement in the learning process.

d) Stimulation of Curiosity

Studies show that participants who generated predictions showed higher levels of curiosity and better recall for correct answers compared to those who only generated examples.

e) Data Analysis

Data was analyzed to measure memory performance, curiosity, and pupil response, which showed that generating predictions increased pupil dilation, an indicator of increased curiosity.

f) Openness and Collaboration

Study results and analysis scripts are made publicly available, enabling transparency and collaboration in educational research.

ISSN 1462 2815

11) Gamification of Learning Content

Learning Content Gamification is the application of game elements in a learning context with the aim to increase student motivation and engagement in the learning process. It can spark curiosity as gamification often includes challenges, point systems, badges or leader boards that encourage students to explore and interact with the learning material in greater depth. Gamification can also provide immediate feedback and allow students to see their progress, which can reinforce curiosity and the drive to keep learning. In the context of the mentioned article, gamification is used to enhance the learning of English grammar in an engaging and interactive way. By tapping into students' epistemic curiosity - the desire to gain knowledge and understanding - and reducing anxiety in language learning, gamification can create a more conducive learning environment that motivates students to engage more deeply with the material being taught.

V. CONCLUSION

This research highlights the crucial role of curiosity in the context of learning motivation, exploring a number of factors that drive it. The drivers of Active Exploration, Intrinsic Motivation, Formation of Generalizable Knowledge and Enhancement of Exploratory Learning prove its relevance as a key driver in the learning process. Not only that, curiosity also contributes significantly to learning outcomes by increasing motivation, questioning skills, and depth of understanding of the material. Furthermore, curiosity is associated with improved memory ability through the activation of Hippocampus and Parahippocampal Gyrus. Effective strategies to trigger curiosity in the learning environment, such as Uncertainty Strategy, exploration, and rewarding, emerge as important elements in stimulating learning motivation. Empirical support from 15 articles highlighting exploration as the most effective strategy, followed by rewarding, confirms the positive correlation between curiosity and learning effectiveness. The main conclusion is that curiosity not only supports the learning process, but also provides the foundation for successful learning strategies.

Future research should focus on several areas based on the context provided. First, it is important to investigate the influence of deactivating emotions, such as relaxation and boredom, in addition to activating emotions such as surprise, curiosity, and confusion [77]. Next, future research should consider other types of knowledge exploration beyond seeking access to correct solutions and additional information. This could involve information exploration that requires more complex and sustained searches, both online and offline [73]. In addition, it would be beneficial to replicate the findings in different types of tasks, such as physical exploration of space and objects [62]. In addition, future research should explore the negative outcomes of curiosity and its effects [58]. Limitations of the study include the inability to fully conclude that uncertainty caused differences in curiosity and transfer outcomes due to other differences between conditions. The timing of curiosity measurements differed between groups, and there was no pre-measure of curiosity for either condition, limiting the understanding of curiosity levels. The low level of internal consistency in the post-test measures of learning raises questions about the accuracy of the learning outcomes. The research design did not allow for independent manipulation of certain variables, and the distinction between curiosity and interest remains unclear. These limitations highlight the need for future research to address these issues and further explore the role of uncertainty, curiosity, and interest in learning outcomes.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Rizki Novendra, Wakhinuddin and Dedy Irfan searched the literature and wrote the first draft of the article. Yogi Yunefri, Adolf Bastian and Nurliana Nasution analyzed and write up draft paper. All authors were involved in completing the final draft of the article

Acknowledgment

We would like to thank colleagues who have contributed to this research, including lecturers and staff. This research activity was also assisted by several team members who were tasked with carrying out the research protocol in order to obtain articles that were in accordance with the research theme. Finally, the researcher also expressed his appreciation and thanks to Lancang Kuning University for providing facilities

References

1) L. Kirsch, J. Harrison, J. Sohl-Dickstein, and L. Metz, "General-Purpose In-Context Learning by Meta-Learning Transformers," 2022, [Online]. Available: http://arxiv.org/abs/2212.04458

2) D. Jackson, J. Fleming, and A. Rowe, "Enabling the Transfer of Skills and Knowledge across Classroom and Work Contexts," *Vocat. Learn.*, vol. 12, no. 3, pp. 459–478, 2019, doi: 10.1007/s12186-019-09224-1.

3) N. B. Dohn, S. B. Hansen, and S. H. Klausen, "On the concept of context," *Educ. Sci.*, vol. 8, no. 3, pp. 1–17, 2018, doi: 10.3390/educsci8030111.

4) D. C. Kristidhika, W. Cendana, I. Felix-Otuorimuo, and C. Müller, "Contextual teaching and learning to improve conceptual understanding of primary students," *Teach. Educ. Res.*, vol. 2, no. 2, p. 71, 2020, doi: 10.33292/ter.v2i2.84.

5) T. Rueterbories *et al.*, "Curiosity as an amplifier of reward-related feedback processing," 2023, [Online]. Available: https://doi.org/10.1101/2023.05.17.540372

6) L. Goupil, J. Proust, L. Goupil, and J. Proust, "Curiosity as a metacognitive feeling To cite this version : HAL Id : hal-03648661 Curiosity as a metacognitive feeling," 2022.

7) T. Sinha, Z. Bai, and J. Cassell, "A new theoretical framework for curiosity for learning in social contexts," *Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics)*, vol. 10474 LNCS, pp. 254–269, 2017, doi: 10.1007/978-3-319-66610-5_19.

8) T. Feraco, E. Sella, C. Meneghetti, and G. Cona, "Adapt, Explore, or Keep Going? The Role of Adaptability, Curiosity, and Perseverance in a Network of Study-Related Factors and Scholastic Success," *J. Intell.*, vol. 11, no. 2, 2023, doi: 10.3390/jintelligence11020034.

9) K. C. J. Eschmann, D. F. M. M. Pereira, A. Valji, V. Dehmelt, and M. J. Gruber, "Curiosity and mesolimbic functional connectivity drive information seeking in real life," *Soc. Cogn. Affect. Neurosci.*, vol. 18, no. 1, 2023, doi: 10.1093/scan/nsac050.

10) M. W. H. Spitzer, J. Janz, M. Nie, and A. Kiesel, "On the interplay of curiosity, confidence, and importance in knowing information," *Psychol. Res.*, vol. 88, no. 1, pp. 101–115, 2023, doi: 10.1007/s00426-023-01841-9.

11) S. Wade and C. Kidd, "The role of prior knowledge and curiosity in learning," *Psychon. Bull. Rev.*, vol. 26, no. 4, pp. 1377–1387, 2019, doi: 10.3758/s13423-019-01598-6.

12) K. E. Twomey and G. Westermann, "Curiosity-based learning in infants: a neurocomputational approach," *Dev. Sci.*, vol. 21, no. 4, pp. 1–13, 2018, doi: 10.1111/desc.12629.

13) F. Alet and M. F. Schneider, "META - Learnıng Curıosıty Algorıthms," pp. 1–22, 2020.

14) "Large-scale study of curiosity-driven learning," *7th International Conference on Learning Representations, ICLR 2019*, no. Query date: 2024-01-18 21:22:51126 cites: https://www.scopus.com/inward/citedby.uri?partnerID=HzOxMe3b&scp=85083953128&origin=inward PG-. 2019. [Online]. Available: https://api.elsevier.com/content/abstract/scopus_id/85083953128 NS -

15) K. L. McNeely-White and A. M. Cleary, “Piquing Curiosity: Déjà vu-Like States Are Associated with Feelings of Curiosity and Information-Seeking Behaviors,” *J. Intell.*, vol. 11, no. 6, 2023, doi: 10.3390/jintelligence11060112.

16) and G. W. Xiaoyun Chen, Katherine E. Twomey, “The role of metacognitive abilities and curiosity in learning,” pp. 2–3, 2020.

17) D. Permatasari, R. Jamaliyah, E. Khoirunnisa, and S. M. A. Lubis, “Curiosity and Learning Motivation Toward Self-Regulated Learning Among Undergraduate Students,” *AXIOM J. Pendidik. dan Mat.*, vol. 11, no. 1, p. 48, 2022, doi: 10.30821/axiom.v11i1.10987.

18) T. Rueterbories, A. Mecklinger, K. C. J. Eschmann, J. Crivelli-Decker, C. Ranganath, and M. J. Gruber, “Curiosity as an amplifier of reward-related feedback processing,” *bioRxiv*, 2023.

19) T. Zhang, V. V Yashin, J. T. Waters, and A. C. Balazs, “The multifaceted role of self-generated question asking in curiosity-driven learning Kara,” pp. 1–9.

20) J. Li and P. Gajane, “Curiosity-driven Exploration in Sparse-reward Multi-agent Reinforcement Learning,” 2023, [Online]. Available: http://arxiv.org/abs/2302.10825

21) C. Chen *et al.*, “Nuclear Norm Maximization Based Curiosity-Driven Reinforcement Learning,” *IEEE Trans. Artif. Intell.*, pp. 1–12, 2023, doi: 10.1109/TAI.2023.3323628.

22) A. Singh and J. A. Manjaly, “Using Curiosity to Improve Learning Outcomes in Schools,” *SAGE Open*, vol. 12, no. 1, 2022, doi: 10.1177/21582440211069392.

23) C. Martínez-Cao *et al.*, “Is it possible to stage schizophrenia? A systematic review,” *Transl. Psychiatry*, vol. 12, no. 1, 2022, doi: 10.1038/s41398-022-01889-y.

24) M. L. Rethlefsen *et al.*, “PRISMA-S: an extension to the PRISMA Statement for Reporting Literature Searches in Systematic Reviews,” *Syst. Rev.*, vol. 10, no. 1, pp. 1–19, 2021, doi: 10.1186/s13643-020-01542-z.

25) C. Cooper, A. Booth, J. Varley-Campbell, N. Britten, and R. Garside, “Defining the process to literature searching in systematic reviews: A literature review of guidance and supporting studies,” *BMC Med. Res. Methodol.*, vol. 18, no. 1, pp. 1–14, 2018, doi: 10.1186/s12874-018-0545-3.

26) S. Fattah, M. Rehn, E. Reierth, and T. Wisborg, “Systematic literature review to identify templates for reporting pre-hospital major incident medical management,” *Scand. J. Trauma. Resusc. Emerg. Med.*, vol. 21, no. S1, p. 2013, 2013, doi: 10.1186/1757-7241-21-s1-s18.

27) E. B. M. Elsman *et al.*, “Study protocol for developing, piloting and disseminating the PRISMA-COSMIN guideline: a new reporting guideline for systematic reviews of outcome measurement instruments,” *Syst. Rev.*, vol. 11, no. 1, pp. 1–13, 2022, doi: 10.1186/s13643-022-01994-5.

28) C. A. Apolaagoa, A.-R. Muhammed, R. S. Zuzie, and A. Owusu, “A Bibliometric Literature Review of Green Supply Chain Management and Its Impacts Using VOSviewer and R (Bibliometrix),” *J. Serv. Sci. Manag.*, vol. 16, no. 03, pp. 369–390, 2023, doi: 10.4236/jssm.2023.163021.

29) D. D. Shin, “Homo Curious: Curious or Interested?,” *Educ. Psychol. Rev.*, vol. 31, no. 4 PG-853–874, pp. 853–874, 2019, doi: 10.1007/s10648-019-09497-x.

30) L. FitzGibbon, “The seductive lure of curiosity: information as a motivationally salient reward,” *Curr. Opin. Behav. Sci.*, vol. 35, no. Query date: 2024-01-18 21:22:5132 cites: https://www.scopus.com/inward/citedby.uri?partnerID=HzOxMe3b&scp=85087482311&origin=inward PG-21-27, pp. 21–27, 2020, doi: 10.1016/j.cobeha.2020.05.014.

31) G. Brod, “Lighting the wick in the candle of learning: generating a prediction stimulates curiosity,” *npj Sci. Learn.*, vol. 4, no. 1 PG-, 2019, doi: 10.1038/s41539-019-0056-y.

32) L. Zheng, “Episodic Multi-agent Reinforcement Learning with Curiosity-driven Exploration,” *Advances in Neural Information Processing Systems*, vol. 5, no. Query date: 2024-01-18 21:22:5116 cites: https://www.scopus.com/inward/citedby.uri?partnerID=HzOxMe3b&scp=85131819610&origin=inward PG-3757-3769. pp. 3757–3769, 2021. [Online]. Available: https://api.elsevier.com/content/abstract/scopus_id/85131819610 NS -

33) C. P. van Schaik, G. R. Pradhan, and C. Tennie, “Teaching and curiosity: sequential drivers of cumulative cultural evolution in the hominin lineage,” *Behav. Ecol. Sociobiol.*, vol. 73, no. 1, 2019, doi: 10.1007/s00265-018-2610-7.

34) J. Litman, “17 Curiosity,” no. May, pp. 418–442, 2018.

35) N. Bougie, “Fast and slow curiosity for high-level exploration in reinforcement learning,” *Appl. Intell.*, vol. 51, no. 2 PG-1086–1107, pp. 1086–1107, 2021, doi: 10.1007/s10489-020-01849-3.

36) S. E. Hidi, “On educating, curiosity, and interest development,” *Curr. Opin. Behav. Sci.*, vol. 35, no. Query date: 2024-01-18 21:22:5119 cites:

https://www.scopus.com/inward/citedby.uri?partnerID=HzOxMe3b&scp=85093696151&origin=inward PG-99-103, pp. 99–103, 2020, doi: 10.1016/j.cobeha.2020.08.002.

37) C. B. Marvin, E. Tedeschi, and D. Shohamy, “Curiosity as the impulse to know: common behavioral and neural mechanisms underlying curiosity and impulsivity,” *Curr. Opin. Behav. Sci.*, vol. 35, pp. 92–98, 2020, doi: 10.1016/j.cobeha.2020.08.003.

38) J. Gottlieb, “Curiosity, information demand and attentional priority,” *Curr. Opin. Behav. Sci.*, vol. 35, no. Query date: 2024-01-18 21:22:5118 cites: https://www.scopus.com/inward/citedby.uri?partnerID=HzOxMe3b&scp=85090715406&origin=inward PG-83-91, pp. 83–91, 2020, doi: 10.1016/j.cobeha.2020.07.016.

39) M. J. Gruber, A. Valji, and C. Ranganath, “The Cambridge Handbook on Motivation and Learning Chapter: Curiosity and Learning: A Neuroscientific Perspective Authors,” *Cambridge Handb. Motiv. Learn.*, pp. 397–417, 2019.

40) T. Post, “Development and validation of a questionnaire to measure primary school children’s images of and attitudes towards curiosity (the CIAC questionnaire),” *Motiv. Emot.*, vol. 43, no. 1 PG-159–178, pp. 159–178, 2019, doi: 10.1007/s11031-018-9728-9.

41) E. G. Liquin, “A functional approach to explanation-seeking curiosity,” *Cogn. Psychol.*, vol. 119, no. Query date: 2024-01-18 21:22:5135 cites: https://www.scopus.com/inward/citedby.uri?partnerID=HzOxMe3b&scp=85079245635&origin=inward PG-, 2020, doi: 10.1016/j.cogpsych.2020.101276.

42) E. Peterson, “Curiosity and interest: current perspectives,” *Educ. Psychol. Rev.*, vol. 31, no. 4 PG-781–788, pp. 781–788, 2019, doi: 10.1007/s10648-019-09513-0.

43) M. C. Narumsari and I. Wilujeng, “Developing Natural Science E-Learning Student Worksheets to Optimize Students’ Curiosity and Science Literacy During Covid-19 Pandemic,” *AIP Conf. Proc.*, vol. 2600, no. May, 2022, doi: 10.1063/5.0113645.

44) S. Wade and C. Kidd, “The role of prior knowledge and curiosity in learning,” *Psychon. Bull. \&review*, 2019, doi: 10.3758/s13423-019-01598-6.

45) J. C. Hong, J. H. Ye, and J. Y. Fan, “STEM in Fashion Design: The Roles of Creative Self-Efficacy and Epistemic Curiosity in Creative Performance.,” *EURASIA J. Math. Sci. …*, 2019, [Online]. Available: https://eric.ed.gov/?id=EJ1311723

46) “04.”

47) Y. Fandakova and M. J. Gruber, “States of curiosity and interest enhance memory differently in adolescents and in children,” *Dev. Sci.*, 2021, doi: 10.1111/desc.13005.

48) J. L. Gorlewicz and S. Jayaram, “Instilling curiosity, connections, and creating value in entrepreneurial minded engineering: Concepts for a course sequence in dynamics and controls,” *Entrep. Educ. …*, 2020, doi: 10.1177/2515127419879469.

49) M. J. Gruber, “How Curiosity Enhances Hippocampus-Dependent Memory: The Prediction, Appraisal, Curiosity, and Exploration (PACE) Framework,” *Trends Cogn. Sci.*, vol. 23, no. 12 PG-1014–1025, pp. 1014–1025, 2019, doi: 10.1016/j.tics.2019.10.003.

50) S. de Mijolla-Mellor, “Incuriosity,” *Clin. Mediterr.*, vol. 102, no. 2, pp. 21–35, 2020, doi: 10.3917/cm.102.021.

51) K. Murayama, “A Reward-Learning Framework of Knowledge Acquisition: An Integrated Account of Curiosity, Interest, and Intrinsic–Extrinsic Rewards,” *Psychol. Rev.*, vol. 129, no. 1 PG-175–198, pp. 175–198, 2022, doi: 10.1037/rev0000349.

52) Y. Chang, “Work curiosity: A new lens for understanding employee creativity,” *Hum. Resour. Manag. Rev.*, vol. 29, no. 4 PG-, 2019, doi: 10.1016/j.hrmr.2018.10.005.

53) K. Nguyen, “Help, Anna! Visual navigation with natural multimodal assistance via retrospective curiosity-encouraging imitation learning,” *EMNLP-IJCNLP 2019 - 2019 Conference on Empirical Methods in Natural Language Processing and 9th International Joint Conference on Natural Language Processing, Proceedings of the Conference*, no. Query date: 2024-01-18 21:25:4559 cites: https://www.scopus.com/inward/citedby.uri?partnerID=HzOxMe3b&scp=85084308845&origin=inward PG-684-695. pp. 684–695, 2019. [Online]. Available: https://api.elsevier.com/content/abstract/scopus_id/85084308845 NS -

54) A. Ten, P. Kaushik, P. Y. Oudeyer, and J. Gottlieb, “Humans monitor learning progress in curiosity-driven exploration,” *Nat. Commun.*, vol. 12, no. 1, pp. 1–10, 2021, doi: 10.1038/s41467-021-26196-w.

55) K. L. Wiggin, M. Reimann, and S. P. Jain, “Curiosity Tempts Indulgence,” *J. Consum. Res.*, vol. 45, no. 6, pp. 1194–1212, 2019, doi: 10.1093/jcr/ucy055.

56) M. Mahmoodzadeh, “Towards Conceptualizing Language Learning Curiosity in SLA: An Empirical Study,” *J. Psycholinguist. Res.*, vol. 48, no. 2 PG-333–351, pp. 333–351, 2019, doi: 10.1007/s10936-018-9606-3.

57) R. L. Cervera, M. Z. Wang, and B. Y. Hayden, “Systems neuroscience of curiosity,” *Curr. Opin. Behav. Sci.*, vol. 35, pp. 48–55, 2020, doi: 10.1016/j.cobeha.2020.06.011.

58) R. Abdelghani *et al.*, “GPT-3-Driven Pedagogical Agents to Train Children’s Curious Question-Asking Skills,” *Int. J. Artif. Intell. Educ.*, pp. 1–38, 2023, doi: 10.1007/s40593-023-00340-7.

59) L. Goupil and J. Proust, “Curiosity as a metacognitive feeling,” *Cognition*, vol. 231, 2023, doi: 10.1016/j.cognition.2022.105325.

60) V. Dean, “See, hear, explore: Curiosity via audio-visual association,” *Advances in Neural Information Processing Systems*, vol. 2020, no. Query date: 2024-01-18 21:25:4518 cites: https://www.scopus.com/inward/citedby.uri?partnerID=HzOxMe3b&scp=85106130006&origin=inward PG-. 2020. [Online]. Available: https://api.elsevier.com/content/abstract/scopus_id/85106130006 NS -

61) Y. H. Fang, “How does participation and browsing affect continuance intention in virtual communities? An integration of curiosity theory and subjective well-being,” *Behav. Inf. Technol.*, vol. 40, no. 3 PG-221–239, pp. 221–239, 2021, doi: 10.1080/0144929X.2019.1685002.

62) E. Ishaq, “Epistemic curiosity and perceived workload: a moderated mediation model of achievement striving and overwork climate,” *Int. J. Hum. Resour. Manag.*, vol. 32, no. 18 PG-3888–3911, pp. 3888–3911, 2021, doi: 10.1080/09585192.2019.1641734.

63) K. Fayn, “Confused or Curious? Openness/Intellect Predicts More Positive Interest-Confusion Relations,” *J. Pers. Soc. Psychol.*, no. Query date: 2024-01-18 21:22:5133 cites: https://www.scopus.com/inward/citedby.uri?partnerID=HzOxMe3b&scp=85068206310&origin=inward PG-, 2019, doi: 10.1037/pspp0000257.

64) Y. Luo, “Curiosity-driven reinforcement learning for diverse visual paragraph generation,” *MM 2019 - Proceedings of the 27th ACM International Conference on Multimedia*, no. Query date: 2024-01-18 21:25:4521 cites: https://www.scopus.com/inward/citedby.uri?partnerID=HzOxMe3b&scp=85074866245&origin=inward PG-2341-2350. pp. 2341–2350, 2019. doi: 10.1145/3343031.3350961.

65) T. Scialom, “Ask to Learn: A Study on Curiosity-driven Question Generation,” *COLING 2020 - 28th International Conference on Computational Linguistics, Proceedings of the Conference*, no. Query date: 2024-01-18 21:25:4512 cites: https://www.scopus.com/inward/citedby.uri?partnerID=HzOxMe3b&scp=85135837013&origin=inward PG-2224-2235. pp. 2224–2235, 2020. [Online]. Available: https://api.elsevier.com/content/abstract/scopus_id/85135837013 NS -

66) M. Shi, “A Curiosity-Based Learning Method for Spiking Neural Networks,” *Front. Comput. Neurosci.*, vol. 14, no. Query date: 2024-01-18 21:25:4511 cites: https://www.scopus.com/inward/citedby.uri?partnerID=HzOxMe3b&scp=85079694263&origin=inward PG-, 2020, doi: 10.3389/fncom.2020.00007.

67) K. Kim, “Active World Model Learning with Progress Curiosity,” *37th International Conference on Machine Learning, ICML 2020*, no. Query date: 2024-01-18 21:25:4510 cites: https://www.scopus.com/inward/citedby.uri?partnerID=HzOxMe3b&scp=85105202868&origin=inward PG-5262-5271. pp. 5262–5271, 2020. [Online]. Available: https://api.elsevier.com/content/abstract/scopus_id/85105202868 NS -

68) N. Bougie, “Skill-based curiosity for intrinsically motivated reinforcement learning,” *Mach. Learn.*, vol. 109, no. 3 PG-493–512, pp. 493–512, 2020, doi: 10.1007/s10994-019-05845-8.

69) F. Röder, “Curious Hierarchical Actor-Critic Reinforcement Learning,” *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, vol. 12397, no. Query date: 2024-01-18 21:25:4510 cites: https://www.scopus.com/inward/citedby.uri?partnerID=HzOxMe3b&scp=85094115054&origin=inward PG-408-419. pp. 408–419, 2020. doi: 10.1007/978-3-030-61616-8_33.

70) J. Metcalfe, “Curiosity and the desire for agency: wait, wait … don’t tell me!,” *Cogn. Res. Princ. Implic.*, vol. 6, no. 1 PG-, 2021, doi: 10.1186/s41235-021-00330-0.

71) T. Nguyen, “Sample-efficient Reinforcement Learning Representation Learning with Curiosity Contrastive Forward Dynamics Model,” *IEEE International Conference on Intelligent Robots and Systems*, no. Query date: 2024-01-18 21:25:455 cites: https://www.scopus.com/inward/citedby.uri?partnerID=HzOxMe3b&scp=85124354646&origin=inward PG-3471-3477. pp. 3471–3477, 2021. doi: 10.1109/IROS51168.2021.9636536.

72) E. G. Liquin, “Quantifying Curiosity: A Formal Approach to Dissociating Causes of Curiosity,” *Proceedings for the 42nd Annual Meeting of the Cognitive Science Society: Developing a Mind: Learning in Humans, Animals, and Machines, CogSci 2020*, no. Query date: 2024-01-18 21:25:455 cites: https://www.scopus.com/inward/citedby.uri?partnerID=HzOxMe3b&scp=85120448003&origin=inward PG-309-315. pp. 309–315, 2020. [Online]. Available: https://api.elsevier.com/content/abstract/scopus_id/85120448003 NS -

73) R. Han, “Curiosity-driven recommendation strategy for adaptive learning via deep reinforcement learning,” *Br. J. Math. Stat. Psychol.*, vol. 73, no. 3 PG-522–540, pp. 522–540, 2020, doi: 10.1111/bmsp.12199.

74) J. J. Jirout, “Supporting Early Scientific Thinking Through Curiosity,” *Front. Psychol.*, vol. 11, no. Query date: 2024-01-18 21:22:5128 cites: https://www.scopus.com/inward/citedby.uri?partnerID=HzOxMe3b&scp=85089855283&origin=inward PG-, 2020, doi: 10.3389/fpsyg.2020.01717.

75) J. T. Huck, “The Role of Epistemic Curiosity in Game-Based Learning: Distinguishing Skill Acquisition From Adaptation,” *Simul. Gaming*, vol. 51, no. 2 PG-141–166, pp. 141–166, 2020, doi: 10.1177/1046878119895557.

76) T. B. Kashdan, “The Five-Dimensional Curiosity Scale Revised (5DCR): Briefer subscales while separating overt and covert social curiosity,” *Pers. Individ. Dif.*, vol. 157, no. Query date: 2024-01-18 21:22:5161 cites: https://www.scopus.com/inward/citedby.uri?partnerID=HzOxMe3b&scp=85078610393&origin=inward PG-, 2020, doi: 10.1016/j.paid.2020.109836.

77) E. Vogl, R. Pekrun, and K. Loderer, “Surprised – Curious – Confused : Epistemic Emotions and Knowledge Exploration,” *Emotion*, vol. 20, no. 4, pp. 625–641, 2020, [Online]. Available: https://centaur.reading.ac.uk/81885/3/Epistemic Emotions R2 Manuscript 12Jan2019.pdf

78) K. Murayama, “Process Account of Curiosity and Interest: A Reward-Learning Perspective,” *Educ. Psychol. Rev.*, vol. 31, no. 4 PG-875–895, pp. 875–895, 2019, doi: 10.1007/s10648-019-09499-9.

79) N. Savinov, “Episodic curiosity through reachability,” *7th International Conference on Learning Representations, ICLR 2019*, no. Query date: 2024-01-18 21:22:5174 cites: https://www.scopus.com/inward/citedby.uri?partnerID=HzOxMe3b&scp=85083950285&origin=inward PG-. 2019. [Online]. Available: https://api.elsevier.com/content/abstract/scopus_id/85083950285 NS -

80) E. Vogl, “Surprise, Curiosity, and Confusion Promote Knowledge Exploration: Evidence for Robust Effects of Epistemic Emotions,” *Front. Psychol.*, vol. 10, no. Query date: 2024-01-18 21:22:5162 cites:https://www.scopus.com/inward/citedby.uri?partnerID=HzOxMe3b&scp=85075806755&origin=inward PG-, 2019, doi: 10.3389/fpsyg.2019.02474.

81) Y. Zheng, “Automatic web testing using curiosity-driven reinforcement learning,” *Proceedings - International Conference on Software Engineering*, no. Query date: 2024-01-18 21:22:5132 cites: https://www.scopus.com/inward/citedby.uri?partnerID=HzOxMe3b&scp=85112295528&origin=inward PG-423-435. pp. 423–435, 2021. doi: 10.1109/ICSE43902.2021.00048.

82) M. Lamnina and C. C. Chase, “Developing a thirst for knowledge: How uncertainty in the classroom influences curiosity, affect, learning, and transfer,” *Contemp. Educ. Psychol.*, vol. 59, no. June, 2019, doi: 10.1016/j.cedpsych.2019.101785.

83) E. G. Liquin and T. Lombrozo, “Explanation-seeking curiosity in childhood,” *Curr. Opin. Behav. Sci.*, vol. 35, no. Figure 1, pp. 14–20, 2020, doi: 10.1016/j.cobeha.2020.05.012.

84) J. C. Hong, M. Y. Hwang, Y. H. Liu, and K. H. Tai, “Effects of gamifying questions on English grammar learning mediated by epistemic curiosity and language anxiety,” *Comput. Assist. Lang. Learn.*, vol. 35, no. 7, pp. 1458–1482, 2022, doi: 10.1080/09588221.2020.1803361.

85) J. Prochaska and N. Benowitz, “乳鼠心肌提取 HHS Public Access,” *Physiol. Behav.*, vol. 176, no. 1, pp. 100–106, 2016, doi: 10.1016/j.cobeha.2020.06.003.Latent.

86) L. L. van Lieshout, F. P. de Lange, and R. Cools, “Why so curious? Quantifying mechanisms of information seeking,” *Curr. Opin. Behav. Sci.*, vol. 35, pp. 112–117, 2020, doi: 10.1016/j.cobeha.2020.08.005.

87) J. Metcalfe, “Version of Record: https://www.sciencedirect.com/science/article/pii/S2352154620300954,” 2020.

88) A. Jaegle, “Visual novelty, curiosity, and intrinsic reward in machine learning and the brain,” *Curr. Opin. Neurobiol.*, vol. 58, no. Query date: 2024-01-18 21:22:5129 cites: https://www.scopus.com/inward/citedby.uri?partnerID=HzOxMe3b&scp=85073006207&origin=inward PG-167-174, pp. 167–174, 2019, doi: 10.1016/j.conb.2019.08.004.

89) M. F. Wagstaff, “Measures of curiosity: A literature review,” *Hum. Resour. Dev. Q.*, vol. 32, no. 3 PG-363–389, pp. 363–389, 2021, doi: 10.1002/hrdq.21417.

90) C. B. Marvin, “Curiosity as the impulse to know: common behavioral and neural mechanisms underlying curiosity and impulsivity,” *Curr. Opin. Behav. Sci.*, vol. 35, no. Query date: 2024-01-18 21:22:5116 cites: https://www.scopus.com/inward/citedby.uri?partnerID=HzOxMe3b&scp=85091014582&origin=inward PG-92-98, pp. 92–98, 2020, doi: 10.1016/j.cobeha.2020.08.003.

91) C. Colas, “Language as a cognitive tool to imagine goals in curiosity-driven exploration,” *Advances in Neural Information Processing Systems*, vol. 2020, no. Query date: 2024-01-18 21:25:4529 cites: https://www.scopus.com/inward/citedby.uri?partnerID=HzOxMe3b&scp=85108219225&origin=inward PG-. 2020. [Online]. Available: https://api.elsevier.com/content/abstract/scopus_id/85108219225 NS -

92) R. Han, K. Chen, and C. Tan, “Curiosity-driven recommendation strategy for adaptive learning via deep reinforcement learning,” *Br. J. Math. Stat. Psychol.*, vol. 73, no. 3, pp. 522–540, 2020, doi: 10.1111/bmsp.12199.

93) T. H. Skarstein, “Curious children and knowledgeable adults–early childhood student-teachers’ species identification skills and their views on the importance of species knowledge,” *Int. J. Sci. Educ.*, vol. 42, no. 2 PG-310–328, pp. 310–328, 2020, doi: 10.1080/09500693.2019.1710782.

94) D. S. Chaplot, H. Jiang, S. Gupta, and A. Gupta, “Semantic Curiosity for Active Visual Learning,” *Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics)*, vol. 12351 LNCS, pp. 309–326, 2020, doi: 10.1007/978-3-030-58539-6_19.

95) E. Ishaq, S. Bashir, Abdul Karim Khan, M. M. Hassan, and R. Zakariya, “Epistemic curiosity and perceived workload: a moderated mediation model of achievement striving and overwork climate,” *Int. J. Hum. Resour. Manag.*, vol. 32, no. 18, pp. 3888–3911, 2021, doi: 10.1080/09585192.2019.1641734.

96) R. L. Cervera, “Systems neuroscience of curiosity,” *Curr. Opin. Behav. Sci.*, vol. 35, no. Query date: 2024-01-18 21:25:4521 cites: https://www.scopus.com/inward/citedby.uri?partnerID=HzOxMe3b&scp=85088520610&origin=inward PG-48-55, pp. 48–55, 2020, doi: 10.1016/j.cobeha.2020.06.011.

97) P. Reizinger and M. Szemenyei, “Attention-based curiosity-driven exploration in deep reinforcement learning,” *ICASSP, IEEE Int. Conf. Acoust. Speech Signal Process. - Proc.*, vol. 2020-May, pp. 3542–3546, 2020, doi: 10.1109/ICASSP40776.2020.9054546.

98) A. Ten, P. Kaushik, P.-Y. Oudeyer, and J. Gottlieb, “Humans monitor learning progress in curiosity-driven exploration,” *Nat. Commun.*, vol. 12, no. 1, p. 5972, Oct. 2021, doi: 10.1038/s41467-021-26196-w.

99) S. Suhirman, “Problem-Based Learning with Character-Emphasis and Naturalist Intelligence: Examining Students Critical Thinking and Curiosity,” *Int. J. Instr.*, vol. 14, no. 2 PG-217–232, pp. 217–232, 2021, [Online]. Available: https://api.elsevier.com/content/abstract/scopus_id/85101540491 NS -

100) L. FitzGibbon, J. K. L. Lau, and K. Murayama, “The seductive lure of curiosity: information as a motivationally salient reward,” *Curr. Opin. Behav. Sci.*, vol. 35, pp. 21–27, 2020, doi: 10.1016/j.cobeha.2020.05.014.

101) Y. Y. Chang and H. Y. Shih, “Work curiosity: A new lens for understanding employee creativity,” *Hum. Resour. Manag. Rev.*, vol. 29, no. 4, pp. 0–1, 2019, doi: 10.1016/j.hrmr.2018.10.005.

102) C. H. Liu, “Curiosity-driven energy-efficient worker scheduling in vehicular crowdsourcing: A deep reinforcement learning Approach,” *Proceedings - International Conference on Data Engineering*, vol. 2020, no. Query date: 2024-01-18 21:25:4522 cites: https://www.scopus.com/inward/citedby.uri?partnerID=HzOxMe3b&scp=85085863800&origin=inward PG-25-36. pp. 25–36, 2020. doi: 10.1109/ICDE48307.2020.00010.

103) R. Abdelghani, “GPT-3-Driven Pedagogical Agents to Train Children’s Curious Question-Asking Skills,” *Int. J. Artif. Intell. Educ.*, no. Query date: 2024-01-18 21:25:455 cites: https://www.scopus.com/inward/citedby.uri?partnerID=HzOxMe3b&scp=85163710566&origin=inward PG-, 2023, doi: 10.1007/s40593-023-00340-7.

104) L. Goupil, “Curiosity as a metacognitive feeling,” *Cognition*, vol. 231, no. Query date: 2024-01-18 21:25:455 cites: https://www.scopus.com/inward/citedby.uri?partnerID=HzOxMe3b&scp=85142393647&origin=inward PG-, 2023, doi: 10.1016/j.cognition.2022.105325.

105) F. Röder, M. Eppe, P. D. H. Nguyen, and S. Wermter, “Curious Hierarchical Actor-Critic Reinforcement Learning,” *Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics)*, vol. 12397 LNCS, pp. 408–419, 2020, doi: 10.1007/978-3-030-61616-8_33.

106) N. Savinov *et al.*, “Episodic curiosity through reachability,” *7th Int. Conf. Learn. Represent. ICLR 2019*, pp. 1–20, 2019.

107) M. Lamnina, “Developing a thirst for knowledge: How uncertainty in the classroom influences curiosity, affect, learning, and transfer,” *Contemp. Educ. Psychol.*, vol. 59, no. Query date: 2024-01-18 21:22:5155 cites: https://www.scopus.com/inward/citedby.uri?partnerID=HzOxMe3b&scp=85067645464&origin=inward PG-, 2019, doi: 10.1016/j.cedpsych.2019.101785.

108) S. Suhirman, S. Prayogi, and M. Asy’ari, “Problem-Based Learning with Character-Emphasis and Naturalist Intelligence: Examining Students Critical Thinking and Curiosity,” *Int. J. Instr.*, vol. 14, no. 2, pp. 217–232, 2021, doi: 10.29333/iji.2021.14213a.