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The Digital Cognitive Partner: A 4P Framework Analysis of Prospective Teacher Creativity in the Age of AI

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Abstract: Prospective teachers must be equipped with creative thinking skills to be able to design innovative mathematics learning media. However, studies on the creativity of prospective teachers are often not comprehensive and tend to focus on only one dimension of creativity. Although the 4P creativity model (Person, Process, Press, Product) provides a comprehensive analytical lens, research that integrates all four dimensions simultaneously in the context of mathematics teacher education is still rare. This study is a qualitative descriptive study that aims to describe and analyze the creativity of prospective mathematics teacher students in developing mathematics learning media. The subjects were eight students of the Mathematics Education study program who were taking the Mathematics Learning Media course and had completed a mathematics learning media development project. Data sources came from students' reflective journals when creating learning media, interview transcripts, and the learning media products that had been created. The collected data were analyzed based on Rhodes' 4P creativity framework: Person, Process, Press, and Product. The product dimension was analyzed descriptively and quantitatively using the Torrance rubric, consisting of four creativity indicators: fluency, flexibility, originality, and development. The Process dimension was analyzed based on Wallas' creative thinking framework: Preparation, Incubation, Illumination, and Verification. The person and press dimensions were then analyzed qualitatively using a thematic analysis approach. The results showed that students with high intrinsic motivation, active involvement in exploring ideas, and the ability to manage technical and time constraints tended to produce more creative and meaningful learning media. The key findings of this study significantly expand and challenge the traditional understanding of the Press dimension. The use of technology, particularly generative AI such as ChatGPT, serves not only as an external tool but also as a digital cognitive environment. AI acts as an interactive, dialogical partner, assisting in brainstorming, developing flowcharts, and solving technical problems, thereby blurring the boundaries between environmental factors (Press) and students' internal thinking processes (Process). This deep integration demonstrates that AI has become an integral part of students' cognitive workflows, implying that the 4P framework in the digital era needs to be viewed as an interconnected and flexible system, rather than as four rigidly separate pillars.

Keywords: creativity, mathematics learning media, creative thinking process, case study, pre-service teachers, artificial intelligence.

▪ INTRODUCTION

The competencies that teachers must possess in 21st-century education, especially in the AI era, include not only mastery of teaching materials but also innovative pedagogical competencies, one of which is the competency in using and creating learning media (Dilling, Schneider, Weigand, & Witzke, 2024; Drijvers, Doorman, Boon, Reed,

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& Gravemeijer, 2010; Goos & Bennison, 2008; Mishra & Koehler, 2006; Najmi, Sinaga, Kuswandi, & Fadhli, 2024). These competencies are important because various studies show that mathematics is a subject that is considered abstract and intimidating for students (Ashcraft, 2002; Boaler, 2016; Nolasco, 2025). By using appropriate learning media, teachers can carry out a fun and meaningful learning process. This fun and meaningful learning is what students need to more easily understand the material presented (Drijvers et al., 2010; Hidayana & Lianingsih, 2025; Muslimah & Witanto, 2025).

The above conditions indicate that universities or teacher education institutions need to provide learning experiences that develop students' creative and innovative thinking skills and not solely focus on mathematical content (Darling-Hammond, 2017; Tondeur, van Braak, Ertmer, & Ottenbreit-Leftwich, 2017; Voogt & Roblin, 2012). In this context, learning that requires students to create mathematics learning media can be used as a practice tool to integrate their knowledge and skills. Through the activity of designing and creating mathematics learning media, students are encouraged to develop reflective, imaginative, and solution-oriented thinking in an effort to address learning challenges in the real classroom (Antonenko & Thompson, 2011; Camelia, Ratyaningrum, Marsudi, & Subagio, 2023; Marlina, Suwono, Yuenyong, Ibrohim, & Hamdani, 2023; Suresh, 2022).

Several experts state that students need to be equipped with creative thinking skills (Goos & Bennison, 2008; Laurillard, 2012; Mawarsari, Astuti, Purnomo, Sediyono, & Purnomo, 2022; Moyer-Packenham & Suh, 2012; Zamzam, 2017), one of which is in developing mathematics learning media. One way to accommodate this is by offering a course on Mathematics Learning Media. In this course, students are not only equipped with theories related to mathematics learning media but are also required to design innovative mathematics learning media individually.

However, the process of fostering student creativity is not simple (Beghetto & Kaufman, 2014; Muñoz-Salinas, Caro-Zúñiga, & Jeria, 2025; Plucker, Beghetto, & Dow, 2004; Sternberg, 2006). Developing student creativity is not an instant process that can be achieved through verbal instruction alone (Henriksen, Mishra, & Fisser, 2016; Scott, Leritz, & Mumford, 2004). This is because creativity is not an innate skill possessed by students, but rather a competency that can be developed through appropriate learning or training (Larraz-Rábanos, 2021; Lemmetty, Collin, Glăveanu, & Forsman, 2021; Rosen, Stoeffler, & Simmering, 2020). Therefore, a conceptual framework is needed to assist lecturers in mapping student creativity.

One conceptual framework related to creativity that is frequently used in various studies is the 4P model, developed by Rhodes (1961). The 4P model consists of four dimensions of creativity: person, process, press, and product. The person dimension relates to individual characteristics, the process dimension relates to the cognitive processes experienced by an individual, the press dimension encompasses the influence of the environment on a person's creativity, and the product dimension relates to the creative work produced. These four dimensions are interrelated and can be used to examine how student creativity develops. The interconnectedness of these four dimensions is the strength of the 4P model. The 4P model recognizes that creativity is a complex phenomenon arising from these four dimensions. The press dimension in this model becomes increasingly relevant because it can be used to analyze external factors that influence students' creative processes in developing mathematics learning media.

However, although the 4P model offers a comprehensive approach, research on students' creativity has tended to focus on only one dimension and has not fully integrated all four dimensions of creativity (Muñoz-Salinas et al., 2025) Several studies in the context of developing mathematics learning media also show similar results. For example, research conducted by (Adinugraha, 2020; Agustinaningsih, 2020; Nurhayati & Rahardi, 2021) focused on the product dimension, while research conducted by (Hidayati & Tristanti, 2023) tended to focus on the process and product dimensions.

Research that focuses solely on one of these dimensions can lead to an incomplete understanding because it ignores how other dimensions of creativity are involved in the formation of creativity. However, having a deep understanding of how students process ideas, respond to environmental factors, and recognize personal potential and obstacles is crucial for developing strategies to foster student creativity.

In the context of the mathematics learning media course, the process of designing and creating learning media serves as a way to observe student creativity. When students are given assignments to create learning media, they not only face technical challenges but are also challenged to think critically, imaginatively, and innovatively. This is where creativity is tested and developed authentically.

Considering the importance of creativity in supporting the pedagogical competence of prospective mathematics teachers and the lack of research that comprehensively explores the dimensions of person, process, press, and product in the context of developing mathematics learning media, this research is very relevant to conduct. This research aims to analyze the creativity of prospective mathematics teacher students in creating learning media using the 4P approach. Specifically, this research focuses on the main question: How does the dynamic interaction between the dimensions of Person, Process, and Press shape the quality of creativity in the Products developed by students? Through this approach, it is hoped that a comprehensive understanding of student creativity in designing and creating mathematics learning media will be obtained. The results of the research are expected to be used as a basis for developing creative learning models for prospective mathematics teachers.

▪ METHOD

Research Design and Procedures

This study employed a qualitative research design, specifically a descriptive case study approach. A case study was deemed appropriate as it allows for an in-depth exploration of a specific phenomenon, the creativity of pre-service teachers, within its real-world context, namely the Mathematics Learning Media course. The research was conducted in a step-by-step manner. The first stage involved the students’ project work in creating mathematics learning media as the final assignment for this course. The development of the learning media was conducted over an eight-week period. During the creation process, students were asked to complete a reflective journal using a provided template. After the media was completed and submitted, the next phase involved conducting interviews with the students. The interviews aimed to gain a deeper understanding of the students' creative processes during the creation of the learning media. The entire research process took place in the even semester of the 2024/2025 academic year, specifically from March to July 2025.

Participants

The population of this study consisted of thirteen students enrolled in the Mathematics Learning Media course at the Mathematics Education Study Program, Satya Wacana Christian University. From this population, a sample of eight students was selected. A purposive sampling technique was used to select the participants. The selection criteria were designed to ensure maximum variation, including: (1) the diversity of media types produced (e.g., board games, digital quizzes, digital games), and (2) the completeness of the descriptions and information written by the students in their reflective journals, which documented their learning process and media development.

In this study, the primary researcher was a lecturer in charge of the Mathematics Learning Media course. To ensure that student responses were natural and candid, several strategies were implemented: 1) students were informed that their participation in the study was voluntary and informed in advance before they created the mathematics learning media as their final project, and that their participation in the study would not affect their grades. 2) The collection of reflective journals by students and the implementation of interviews were carried out after the process of inputting course grades into the system (SIASAT) had been completed. 3) At the beginning of the interview, students were reminded to answer questions truthfully according to what they experienced.

Instruments

Three main instruments were used in this study: a media creativity rubric, a reflective journal, and an interview guide. A description of each instrument is as follows. The media creativity rubric in this study adapts Torrance's (1994) four components of creative thinking: fluency, flexibility, originality, and elaboration. The indicators for each component are contextualized for mathematics learning media. Each component is assessed using a scale of 1-4. The complete rubric is available in Appendix A. To ensure reliability, each product was independently scored by two raters (the researcher and a colleague). The level of inter-rater agreement was analyzed using the Intraclass Correlation Coefficient (ICC) with the assistance of JASP software. The results indicated good agreement levels for the components of fluency (ICC = 0.837), flexibility (ICC = 0.896), originality (ICC = 0.851), and elaboration (ICC = 0.896). Overall, the rubric demonstrated excellent reliability, with a combined ICC score of 0.975, indicating a high level of consistency in the assessment process. The final score was obtained through discussions between assessors to resolve any discrepancies.

The reflective journal in this study was designed to understand students' creative processes during the creation of learning media. This reflective journal consists of three phases: the initial phase, the middle phase, and the final phase. The initial phase was used to record the students' creative process during the first and second weeks. In this phase, questions focused on the process of forming the media idea (Process), the internal factors influencing it (Person), and the final goal of the media developed (Product). The next phase was the middle phase of the project, namely the third to sixth weeks. In this phase, questions related to the development and challenges experienced by the students are addressed. The questions in this phase aimed to obtain important information regarding the creative process, namely the Process dimension (Incubation, Illumination, Verification) and the Press dimension experienced by the students. In the final phase (weeks seven and eight), questions focused on student reflection. There are four questions in this section used to elicit their opinions regarding the media developed (product dimension) and reflections on their personal development during their individual development of mathematics learning media (Person).

The third research instrument was a semi-structured interview guide. The interview guide in this study was structured to explore students' creative processes in creating learning media, specifically within the 4P framework (Person, Process, Press, and Product). The questionnaire was structured according to Wallas' four stages of creative thinking: preparation, incubation, illumination, and verification. However, several specific questions were used to explore the interactions between each dimension of creativity, for example: where did your greatest source of inspiration come from? What do you think most helped or stimulated your creativity in this project? How different is the final product from your initial concept? What prompted these changes?

Data Analysis

The data analysis in this study used the six stages of analysis proposed by Braun & Clarke (2006): Familiarizing yourself with the data, Generating initial codes, Searching for themes, Reviewing themes, Defining and naming themes, and Producing the report. In the Familiarizing yourself with the data stage, the researcher transcribed interviews for each research subject. Next, the researcher repeatedly read the students' reflective journals and interview transcripts to gain an understanding of the creative process each student experienced. During this process of reading and understanding the original data, the researcher began to note interesting points related to the research objectives. In the Generating initial codes stage, the researcher began coding the data. Coding was conducted deductively and inductively. Deductive coding was implemented based on (Wallas, 1926) stages of creative thinking, which consist of preparation, incubation, illumination, and verification. Inductive coding was used to assign codes to the data found, even though it was not directly related to Wallas's creative thinking process. For example, from the R2 data analysis, statements were found such as "curious about Scratch," "created ten untitled projects," "continued to yield in Scratch despite suggestions to move," "frustrated with technical bugs," and "Aha! moment when successfully creating a button." These sentences were assigned initial codes, including curiosity, persistence in experimentation, never giving up on mastering new applications, technical obstacles, and creative breakthroughs. The next stage was searching for themes. At this stage, the researcher began to group the initial codes found into the 4P framework (Person, Process, Press, and Product). For example, the initial codes titled curiosity and persistence in experimentation were used to create a potential theme titled internal motivation. Next, the initial codes "never giving up on mastering new applications," "technical obstacles," and "creative breakthroughs" were used to create a potential theme titled "technical persistence that results in a deep learning experience." In the reviewing theme stage, the initial themes were re-examined. For example, the two initial themes titled "internal motivation" and "technical persistence produces profound learning experiences" turned out to be related and were combined into a theme called "internal motivation that drives technical persistence." The next stage was defining and naming themes. At this stage, the researcher gave names and clearly defined them. For example, the theme called "internal motivation that drives technical persistence" was defined as R2's internal drive that supported his persistence in overcoming technical obstacles and supporting a resilient creative process. The final stage was producing the report. At this stage, the researcher created a narrative of the findings obtained.

It should be noted that in this study, the data analysis process was carried out by the first author. To reduce researcher bias and ensure data validity, this study employed several strategies, including source triangulation, peer debriefing, and member checking. Source triangulation was conducted by comparing data from the reflective journal, interview transcripts, and learning media products. For example, in the reflective journal, information was found that during the idea-searching stage, subject R1 was interested in developing an RPG-based game. Due to her desire to create an RPG game, she chose Cartesian coordinates as the material, considering them suitable for the game she wanted to develop, particularly in the navigation and character movement sections. R1's reflective journal also stated that she explored several sites, including Freepik, Chat GPT, and Canva. R1 also stated that she had considered using other platforms such as Scratch, Construct, and Adobe Animate. However, due to various considerations, she ultimately decided to use GDevelop. R1 statement written in the reflective journal is supported by the data contained in the interview transcript. The interview transcripts also revealed that ChatGPT was predominantly used during the ideation stage, as a tool for exploration and providing input on applications to be used in game development. Comparing the data from the reflective journal and the interview transcripts, it can be interpreted that R1 undertook a thorough preparation process, engaging in in-depth exploration using various applications to brainstorm material and applications to create media based on personal interests. Peer debriefing involves discussing the results of the initial analysis with colleagues to gain a deeper understanding of the findings. For example, in data analysis on the person dimension, the researcher and colleague discuss data groupings such as interests, motivations, adaptive strategies, and each subject's response to the feedback they received. This discussion provides feedback and helps clarify the boundaries between the person and press dimensions. Finally, member checking occurs. The researcher's interpretation of the research results is then confirmed with the subjects to ensure they align with their experiences.

▪ RESULT AND DISSCUSSION

Personal Characteristics in the Creative Process (Person Dimension)

The Person dimension in creativity refers to individual characteristics such as interest, motivation, personal strategies, and students’ adaptability in expressing creative ideas (Aziz, 2023; Beghetto & Kaufman, 2007; Rhodes, 1961; Runco & Acar, 2012). The findings of this study indicate that variations in personal characteristics influence the depth of the creative process and the quality of the instructional media produced.

Most students demonstrated intrinsic motivation as their main driving force. For instance, R1 and R2 expressed a particular interest in programming and game development, which encouraged them to explore platforms such as Scratch, G-Develop, and Construct more extensively. Likewise, R3, R7, and R4 showed interest in specific mathematical topics such as probability, plane figures, and statistics. “...for the type of media, it’s Scratch... Actually, I wanted to know, Sir, what Scratch is. Because I saw it on YouTube when Mr. Danang assigned something on Desmos, I think... that’s when Scratch came up. So I got curious...” (R2, Interview) Such strong interests motivated students to work with persistence and generate more original ideas (Hennessey & Amabile, 2010; Kadyirov, Oo, Kadyjrova, & Józsa, 2024; Zeng, Yan, & Zhang, 2025).

However, not all creative outputs stemmed from initial interest. R3 and R5 explicitly stated that they created this learning media solely as a requirement for a course assignment. “Because this is an assignment, I'll do it” (R3, Interview). However, both subjects demonstrated their creativity through digital exploration, such as watching video tutorials on YouTube and using AI assistance. “At first, I was confused, sir… I was told to create media, and I didn't know what to make or how… so I relied on tutorials… from YouTube.” (R5, Interview)

This situation demonstrates that creativity can grow in situational contexts, especially when faced with challenging assignments (Beghetto & Kaufman, 2007; De Alencar, De Souza Fleith, & Pereira, 2017; Lestari & Zakiah, 2019). This situational creativity forms the main foundation of project-based learning in the digital age (Anggraeni, Abdulkarim, & Jupri, 2019; Diani, Susanti, Widiawati, & Velina, 2025).

Regarding adaptive strategies, most students demonstrated the ability to cope with constraints. They searched for tutorials on YouTube and discussed them with friends. They experimented through trial and error to overcome various challenges, such as time limitations, technical difficulties, and a lack of digital resources. "From a technical perspective, I faced challenges in designing game boards and cards that were visually appealing yet functional… To overcome these difficulties… I also learned to use Canva to design more visually appealing elements." (R7, Reflective Journal)

This demonstrates the presence of creative coping strategies, a key aspect of creativity development, which enhances students' cognitive flexibility (Cheng & Cheung, 2005; Craft, 2005; Wu & Koutstaal, 2020; Xu & Wang, 2022). This flexibility is a hallmark of adaptive creativity, or the ability to change strategies when faced with obstacles (Lemmetty et al., 2021).

The use of YouTube, Canva, and ChatGPT demonstrates that digital technology plays a significant role in supporting student creativity. Five of the subjects in this study (R1, R2, R3, R6, and R7) stated that they utilized AI, such as ChatGPT, as a tool for generating ideas or solving problems or obstacles they faced, such as helping fix coding issues or conceptualizing their media designs.

Feedback from lecturers and peers was also appreciated by almost all participants. For example, R5 stated that she added explanatory videos to the learning media she created after receiving feedback from her lecturer. Similarly, R3 commented that, following a suggestion to create mathematics learning media that served more than just practice problems, she modified the developed media by adding "cards" to support the explanations of the concepts in the chosen material. This shows that suggestions from their lecturers encouraged them to add more interactive features. These findings support research by Torrance (1988) and Hennessey & Amabile, 1987, 2010) that creativity can be enhanced in a supportive learning environment.

Overall, the Person dimension in this study indicates that student creativity is shaped by the interaction between interest or internal motivation, task demands, responses to obstacles and challenges, use of digital technology, and a supportive learning environment. A thematic summary of the eight participants is presented in Table 1.

Table 1. Thematic summary of the person dimension

No	Name	Personal Interest	Help Seeking Tendencies	Adaptive Strategies	Role of Feedback
1	R3	Visualization	Peers, Lecturer, ChatGPT	Tutorials, gradual revisions	Helped expand important ideas
2	R1	RPG Game	ChatGPT, prior experience	Use of AI, personal logic	Considered less relevant
3	R5	None	Peers, YouTube, Canva	Experimentation, discussion	Added explanatory video feature
4	R6	None (initially)	YouTube, AI, ChatGPT	Topic shifting, digital exploration	Enriched design and interaction
5	R7	Boardgame	Peers, ChatGPT	Canva, discussions, trial and error	Helped simplify design
6	R4	Statistics	Peers, YouTube	Iterative revisions	Unique ideas, especially on dice functionality
7	R8	Animated video	Peers, YouTube	Own voiceover, character modifications	Feedback improved the product
8	R2	Scratch (curiosity-driven)	ChatGPT, R1, Lecturer	Repeated trials, experimentation	Led to a change in the technical approach

Creative Process Stages of Students (Process Dimension)

Students' creative thinking processes in designing mathematics instructional media were analyzed using Wallas' four-stage creative process framework: Preparation, Incubation, Illumination, and Verification. The following is an explanation of each stage.

Preparation: Initial Exploration and Personal Interest

The preparation stage in the process dimension can be defined as the stage where a person defines a problem, understands it, and gathers information to solve it (Botella, Zenasni, & Lubart, 2018; Carson, 1999; Sawyer, 2021). In this study, the preparation stage is characterized by students searching for ideas to develop learning media. Several subjects who already had specific motivations or interests stated that they explored the application to use to create learning media. For example, subject R1 stated that she was very interested in creating an RPG game. This led her to explore various websites to determine whether to use Adobe Animate, Construct, Scratch, or GDevelop to create her digital game. "I have been interested in creating an RPG-style educational game from the start." (R1, Reflective Journal)

Other subjects stated that they sought media development ideas by first selecting mathematics material. Some students immediately chose certain topics, such as fractions or GCF and LCM, because they felt they were easy. Another student, such as R3, stated that she researched topics by reading relevant CPs. On the other hand, R6 stated that she combined the task of creating learning media with assignments in other courses into one project to be more effective. R6's initial idea regarding the media to be created was influenced by the support of colleagues from the Information Systems study program. This shows that the Preparation phase involves not only technical planning but also personal experiences and social influences (Runco & Acar, 2012).

Incubation: Exploration, Pause, and Meaning-Making

The incubation stage is the stage where a person disengages from trying to solve the problem at hand (Sawyer, 2021; Sio & Ormerod, 2009; Wallas, 1926). In this study, the incubation stage occurred when students encountered obstacles in designing or creating learning media, such as designing the media, adding features, or experiencing technical challenges. For example, R3 stated that she felt stuck when she had difficulty transforming her ideas into a design for the media she wanted to develop. At this stage, she chose to focus on other tasks first. "I did not skip it, I kept doing other tasks, like going somewhere."

R7 experienced a similar situation. She experienced a dead end when considering how to modify the media she had created so that it could be used to introduce mathematical concepts, not just for practice problems. At this stage, she tried asking questions in the ChatGPT and Perplexity chats but found no answers. This caused her to pause and take a break. "At that time, the game was already finished, with gameplay instructions and so on. It turned out that there needed to be a concept introduction. There was a dead end. I did not know how to incorporate the concept introduction part because the media was already finished, and there needed to be a concept introduction. I tried asking AI, ChatGPT, and Perplexid, but could not find an answer. So I stopped for a while to refresh myself." (R7, Interview)

Subject R2 also attempted to explore using digital technology when she encountered technical issues setting up broadcasts and variables in Scratch. She stated that the Next button didn't work, which frustrated her greatly, and she considered giving up. She attempted to solve the problem by exploring ChatGPT to learn to understand the logic flow in Scratch. "Although it did not work immediately, I slowly began to understand the error patterns. I learned that the order of broadcasts and variable resets significantly affects the program's execution." The use of digital technology to support the process of creating learning media aligns with Craft's (2005) view of technology as a creative driver.

Illumination: Emergence of Key Ideas and Creative Insights

The illumination stage occurs when someone suddenly discovers a creative idea (Botella et al., 2018; Carson, 1999). Eight subjects in this study reported experiencing 'aha' moments in various ways. R8 accidentally came up with the idea to add characters to the animated video she was creating. "My intention was just to use voices, and then I thought, 'What if I add characters... That's what I thought about it?'" (R8, Interview)

Meanwhile, R1, R2, and R4 experienced this moment after conducting various experiments. "One of those 'Aha!' moments was a moment. What I experienced was when I successfully made the NEXT button work according to a specific step, simply by adding an if condition that checked the value of a variable. This opened my eyes to the fact that technical solutions are sometimes simple; we just needs to look at it from a different angle." (R2, Reflective Journal)

These "aha" moments are usually accompanied by a sense of satisfaction and joy, signifying the integration of old and new knowledge, known as creative insight (Sawyer, 2021). "It felt good, like a sense of relief." (R4, interview)

Verification: Media Refinement and Finalization

The verification stage is the stage where someone evaluates, tests, and refines their ideas (Botella et al., 2018; Carson, 1999; Sawyer, 2021). In this study, subjects experienced the verification stage when evaluating, testing, or refining concepts, problem-solving, and reflecting on their media ideas or products. The verification stage also involves external parties. For example, R7 stated that she sought external evaluations from lecturers and friends to verify the quality and suitability of her media ideas for students. "I seek inspiration from friends outside of campus, like asking, 'How is this good?', 'Is this like this enough?'" (R7, Interview)

R1 also conducted a similar experiment, testing the media she had developed with friends and seniors. Although the details were not explicitly explained, this trial process could indicate that she was trying to verify the quality and user experience of the media she had created. "So far, only my friends, including seniors, have tried it. The feedback so far has been good, but it is like saying, 'What are you doing so hard?'"

Another finding was that several students reflected on the limitations and potential of the media they had created. R5 and R6 recognized that the quality of their media could be improved with more time to work on it. These findings confirm that creativity continues after the product is finished, developing through reflection and self-evaluation (Beghetto & Kaufman, 2007; Zimmerman, 2002). A summary of the students' creative process stages is presented in Table 2.

Table 2. Summary of students' creative process stages

No	Name	Preparation	Incubation	Illumination	Verification
1	R3	Board game, real-life probability, snakes-and-ladders analogy	Simplifying concepts, consulting a lecturer, and reading elementary textbooks	Multi-sided dice idea, integration of narration and reflection into cards	Prototype finalization, evaluation, media meaning, and learning process reflection
2	R1	RPG game, GDevelop, Canva, visual exploration, platform selection	Coding errors, ChatGPT usage, paused development, experienced stagnation, and reflection	Programming success, design changes efficiency idea emerged post-failure	Debugging and navigation logic, external evaluation, game completion, and final reflection
3	R5	Choose the fractions topic, interactive quiz, and tiered questions	Hesitation with no story-based questions, reflection on simplicity	The repetition system idea and the tiered question structure as a learning strategy	Canva design finalization, button/slide check, media effectiveness reflection
4	R6	Choose LCM & GCF, self-paced digital quiz concept, integrated assignments	Technical challenge with random questions and visuals, collaboration with a peer	Use of animated GIF background, added background music, simplified logic	Interface and functionality finalized, tested across devices
5	R7	Chose area & perimeter topic,	Challenges in question design,	The card "chance" idea turned into	Design finalization, pedagogical and

		Monopoly-inspired, decided to make a board game	game flow, visual design, and time management	real-life exploratory activities for active, contextual learning	visual reflection, awareness of student empathy importance
6	R4	Choose basic statistics, inspired by UNO and adventure board games	Difficulty integrating questions and gameplay, technical design challenges with cards and board	Narrative problems based on adventure stories (e.g., animal footprints)	Design finalization, pedagogical and visual reflection, awareness of media as a conceptual bridge
7	R8	Choose integer operations, a video idea inspired by COVID-era learning	Difficulty visualizing subtraction, time constraints	Solution: added voice-over and humorous characters to capture students' attention	Video finalization, reflection on precision, and conceptual understanding
8	R2	Choose number patterns, a detective game concept in Scratch	Frustration with the broadcast feature, non-functional buttons	Found "if" logic solution, expanded narrative, and visual elements	Game structure completed, technical evaluation, and reflection on visuals and content

Students' Creative Environment (Press Dimension)

The Press dimension in creativity studies refers to the influence of external factors that either support or hinder an individual's creative process (Rhodes, 1961). In this study, the creative environment experienced by students emerged through the dynamic interaction of social support, digital technology use, task-related pressures, and adaptive strategies developed during the process of designing instructional media.

Social and Academic Support as Creative Stimulus

One factor that plays a role in helping students develop media ideas and improve or refine them is support from lecturers and peers. Feedback provided by lecturers and peers when they presented their media progress encouraged them to evaluate their initial ideas. For example, R3 and R5 revised their projects after receiving suggestions that the media should not merely function as practice tools but also facilitate deeper conceptual understanding. "It was very helpful, sir, because initially, I had not thought about adding learning videos." (R5, Interview)

In addition to the media progress presentation sessions, the discussions they had with their peers outside of class also generated several creative ideas, especially when they encountered obstacles. For example, R4 and R7 explicitly stated that their peers helped and encouraged their creativity in creating this learning media project. "The suggestions from my friends were also suggestions from my friends during discussions" (R4, Interview).

However, not all of the suggestions made by their peers were followed up on by the subjects. R1 stated that she did not follow up on her friend's suggestion because she considered it complicated. "But usually I do not use the suggestions because they are complicated." (R1, Interview)

Technology and AI: Extending and Challenging the Press Dimension

The results show that digital tools were intensively used by the subjects in this study. Five of the eight students explicitly mentioned that ChatGPT helped them generate ideas, discuss ideas, organize media flows, and even solve technical problems. This intensive use of generative AI not only supports the importance of the learning environment but also expands and challenges the traditional definition of the press dimension.

Initially, the Press dimension referred to the social and physical environment, such as peer collaboration or instructor feedback (Glăveanu, 2014; Kaufman & Beghetto, 2009; Rhodes, 1961; Runco, 2014). However, this research finding compels a redefinition of Press to include the digital cognitive environment, where non-human agents act as dynamic partners in the creative process. This finding extends the framework by introducing a new type of environmental influence that is distinct from traditional resources.

Unlike books or other static digital tools, students use ChatGPT to interact and engage in discussions. For example, R1 and R2 explicitly stated that they engaged in dialogue and sought advice from ChatGPT. "I consulted with ChatGPT, and they showed me the codes, and if there were any coding errors, I also consulted with ChatGPT." (R2, Interview). "At that time, I consulted with ChatGPT, and then I added that I wanted to and was interested in making an RPG-type game. Then ChatGPT suggested using coordinate point material... After that, ChatGPT suggested that instead of using Construct, use G-Develop because it can output things like web applications or mobile apps." (R1, Interview)

This situation demonstrates the interaction of communication and collaboration between the subjects and ChatGPT, something that previously could only be done with a human or a peer. This demonstrates that AI functions as an interactive cognitive scaffold, a form of learning support provided actively and dynamically (two-way) with the aim of fostering the development of students' thinking processes, accelerating ideation, and overcoming technical barriers. Thus, it can be said that AI not only provides students with the information they need but also participates in developing solutions and shaping their thought processes. This situation demonstrates that AI also actively participates in the process dimension.

AI's deep involvement in the process challenges the clear boundaries between the press and process dimensions. When students use ChatGPT to discuss or code, is ChatGPT merely an external environmental factor (Press) or has it become an extension of the student's cognitive workflow (Process)? The boundaries between these two dimensions become blurred. ChatGPT is no longer merely present in the environment, but it plays an active role in the thought process itself. This suggests that in the AI era, the 4Ps framework may need to be viewed not as four separate pillars but as a flexible and interconnected system. This challenges the reconsideration of traditional notions of creative agency and authorship when the final product is the result of a seamless human-AI collaboration.

Contextual Pressure

Students experience various pressures while creating mathematics learning media. These pressures range from limited time, equipment, and the sheer number of tasks they must complete. R5 and R6 stated that time constraints were the most significant pressure. They had to work late into the night, even staying up late to complete the media. "I am just pressed for time, sir, because there are so many other courses with assignments, so I think the difficulty is managing my time." (R6, Interview)

Another subject, R1, experienced severe pressure when the media file she was developing became corrupted and could not be opened, requiring her to create it from scratch. This situation was exacerbated by her device (laptop) becoming unusable due to excessive workload. "It culminated at the end of the third week, when the main project file became corrupted and could not be opened; the cloud backup was also empty due to failed synchronization... The laptop starting to lag (being used for almost 20 hours a day) added to the pressure" (R1, Interview).

Furthermore, R8 stated that the main stress came from the large number of college assignments, church services, and numerous meetings, which resulted in difficulties with time management. "Because I have a lot of other college assignments, and I also serve in organizations, there are a lot of meetings. So I do not manage my time well. So I push myself until really late at night, even early in the morning. Sometimes I do not sleep just to work on this." A summary of the students' crises is presented in Table 3.

Table 3. Summary of students' creative environment (press dimension)

No	Name	Social Support	Digital Support	Environmental Pressure
1	R3	Lecturer, peers	YouTube, ChatGPT	Time constraints
2	R1	R2 (peer), mostly self-driven	ChatGPT, GDevelop	Coding errors, slow laptop, limited time
3	R5	Lecturer, peers	CapCut, Canva	Difficulty managing time
4	R6	Friend (Information Systems)	YouTube, coding forums, AI	Piled-up assignments
5	R7	Peer discussions	Canva, YouTube	Time pressure
6	R4	Peer discussions	Canva, YouTube	Board visual design
7	R8	Lecturer, peers	YouTube, Canva	Late-night work, voice narration
8	R2	Lecturer, R1	ChatGPT, Scratch	Coding errors, button issues

Students' Creative Products (Product Dimension)

The Product dimension of creativity refers to the tangible results of students' creative thinking processes, in this case, the learning media they design. In this study, the learning media they created were assessed using four creativity indicators: fluency, flexibility, originality, and elaboration. The assessment results for each media can be seen in Table 4 below.

Table 4. Summary of students' creativity scores and categories (product dimension)

No	Name	Media Title	Fluency	Flexibility	Originality	Elaboration	Total Score	Creativity Category
1	R1	*The Lost Coordinates*	3	4	3	4	14	Highly Developed
2	R2	*Pattern Detective*	3	4	3	3	13	Highly Developed

3	R3	*Dice Adventure*	3	2	2	3	10	Developed
4	R4	*Statventure*	2	2	3	2	9	Developed
5	R5	*Fraction Puzzle Interactive Quiz*	2	3	2	2	9	Developed
6	R6	*Kalifak (KPK & FPB Interactive)*	3	3	2	4	12	Developed
7	R7	*Mathpoly*	2	2	2	2	8	Adequately Developed
8	R8	*Number Learning Series (Addition & Subtraction)*	3	3	2	3	11	Developed

Two students, R1 and R2, fell into the highly developed category. Both students demonstrated fluent idea generation, a flexible, original approach, and well-executed, detailed execution. R1 developed a learning media titled "The Lost Coordinates," designed as an RPG game. This media featured a well-designed visual and engaging storyline. Furthermore, it was highly interactive, enabling users to actively participate in the gameplay.

Next, R2 developed a media called "Detective Pola." This media was used for learning number patterns. Besides being interactive, allowing students to input answers, the storyline was structured in a way that was highly engaging and effectively explained the concept of number patterns. Both R1 and R2 demonstrated a deep understanding and technical mastery of creative learning strategies.

Most students fell into the "Developed" category. They demonstrated promising creative potential and initiative, although some limitations were observed in one or more assessment dimensions. For instance, R6's "Kalifak" scored well in structure and elaboration but lacked originality. R3's Dice Adventure presented a well-conceived board game inspired by Snakes and Ladders, but flexibility in format was still limited. R8 combined hand-drawn animations and self-narration in a math video, yet the interactive component could be further improved. R4 and R5 each presented unique strengths, narrative adventure in a board game and a leveled quiz system on fractions, respectively, but their products lacked a distinct creative signature.

One student, R7, was classified under the Adequately Developed category. Her product, Mathpoly, attempted to blend geometry content with Monopoly-style gameplay. Although the concept was promising, the execution remained relatively basic and did not leverage technology to its full potential. This indicates room for improvement, particularly in terms of design depth and media integration. To provide a clearer picture of the characteristics of each media product, a summary of student work documentation is presented in Table 5.

Table 5. Student media documentation

No	Name	Media Title	Topic	Platform	Key Features	Link/Preview
1	R1	*The Lost Coordinates*	Cartesian Coordinates	GDevelop + RPG	Map navigation, sound effects, and mission system	Link
2	R2	*Pattern Detective*	Number Patterns	Scratch, CapCut	Visuals, symbols, audio narration, interactive quiz	Link

3	R3	*Dice Adventure*	Probability	Canva, Print	Explains concepts + practice activities	Link
4	R4	*Statventure*	Statistics	Canva, Print	Explains concepts + practice activities	Link
5	R5	*Fraction Puzzle Interactive Quiz*	Fractions	Canva	Includes instructional video, multi-level quizzes	Link
6	R6	*Kalifak*	LCM and GCF	Website	Comprehensive, interactive, cross-device accessible	Link
7	R7	*Mathpoly*	Plane Geometry	Canva, Print	Features "chance cards" for contextual exploration	Link
8	R8	*Number Learning Series (Addition & Subtraction)*	Addition & Subtraction	FlipaClip	Animated video, includes practice questions	Link

From Scores to Profiles

The creativity profile is mapped using four indicators from Torrance's framework: Fluency, Flexibility, Originality, and Elaboration. This creativity profile can be seen in Figure 1 below.

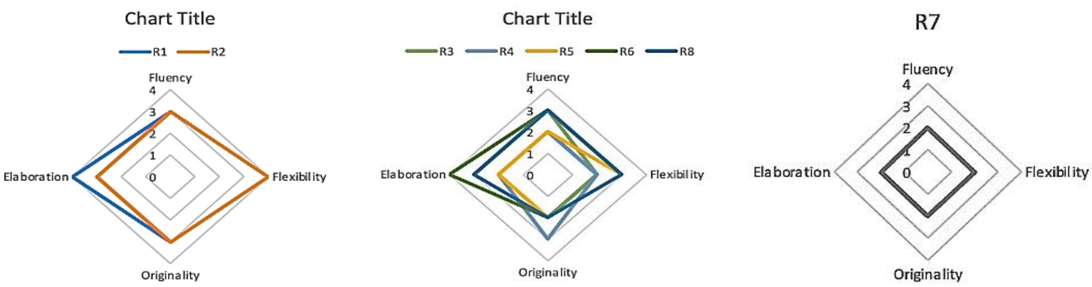

Figure 1. Students creativity profile

The Highly Developed Profile: The Balanced Innovators

The profile of students in the Highly Developed category is characterized by a broad and expansive form, indicating good performance across all four indicators. This balanced product profile is closely related to their Person dimension. R1 has strong internal motivation and views technical challenges not as obstacles. Her tenacity in facing challenges and never giving up is clearly evident in the media creation process. Her ability to interpret pressure as an opportunity for improvement reflects strong reflective attitudes and adaptive strategies, two key indicators of success in project-based learning environments (Craft, 2005). Similarly, R2, her media development was driven by a strong curiosity about Scratch. This curiosity fueled her persistence in continuing to experiment to ensure the resulting media met her expectations. This proactive and learning-oriented attitude is characteristic of this group.

The Developed Profile: The Specialized Creators

The diagram above shows that students in this category have focused profiles that indicate their individual strengths and weaknesses. For example, R6's Kalifak excels in the Elaboration indicator due to its neat and professional website, but scored low on the Originality indicator. R6's profile focuses heavily on aesthetics. "So, beautifying my media is because it (the background) has a gift (image format), like movement." (R6, Interview)

Another profile in this category is shaped by extraordinary dedication. Despite facing time constraints, R8 demonstrated commitment to completing his learning media. As a result, she successfully created a well-developed learning video. “But there is not enough time, sir. So, it is like forcing your own body. Just do it like that. Whether you sleep or not, it is up to you, sir... I can not sleep for two days like that” (R8, Interview)

The Adequately Developed Profile: The Conventional Practitioner

As seen in the figure above, R7's profile narrows down to all aspects, indicating low scores for each indicator. This profile reflects a Person and Process profile that tends to avoid risk. She explicitly chose to develop non-digital learning media because she realized she lacked the skills needed to develop digital learning media. "Honestly, it was me who was the biggest obstacle, because I am not very proficient in, what do you call it, like digital applications" (R7, Interview).

This led her to choose a familiar game concept, namely Monopoly, a game concept she had tried to create in a previous course. This subject's creative process was highly reactive. She stated that her changes were based solely on external feedback. This condition resulted in her media functioning well, but being very conventional.

Relationship of AI Involvement with Learning Media Products

The results of the study indicate that AI involvement in the media creation process can be analyzed more deeply by connecting it to product dimensions. The diagrams below show the relationship between the level of AI involvement carried out by each research subject and the aspects of fluency, flexibility, originality, and elaboration. The level of AI involvement in this context is not simply based on frequency, but also on the nature of the interaction. A more detailed categorization of each subject's level of AI involvement is presented in Table 6.

Table 6. The level of AI involvement

Subject	Category Engagement	Nature of AI Usage	Stages of Usage
R1	High	Cognitive Partner (Consultant, Tutor, Debugger)	Ideation, Technical Planning, Media Creation
R2	High	Cognitive Partner (Concept Generator, Tutor, Debugger)	Ideation, Media Creation, Problem Solving
R3	Medium	To find ideas	Ideation, Concept Development

R6	Medium	Functional Tools (Content Generator, Feature Consultant)	Content Development, Design Features
R7	Low	Initial Information Sources	Initial Ideation
R4	None	-	-
R5	None	-	-
R8	None	-	-

Fluency

The distribution of each student's fluency category scores can be seen in Figure 2 below. Scores for subjects with high, medium, and low AI involvement are indicated by red, green, and orange dots, respectively. Blue dots indicate scores for subjects who did not use AI. This pattern applies to other aspects of creativity.

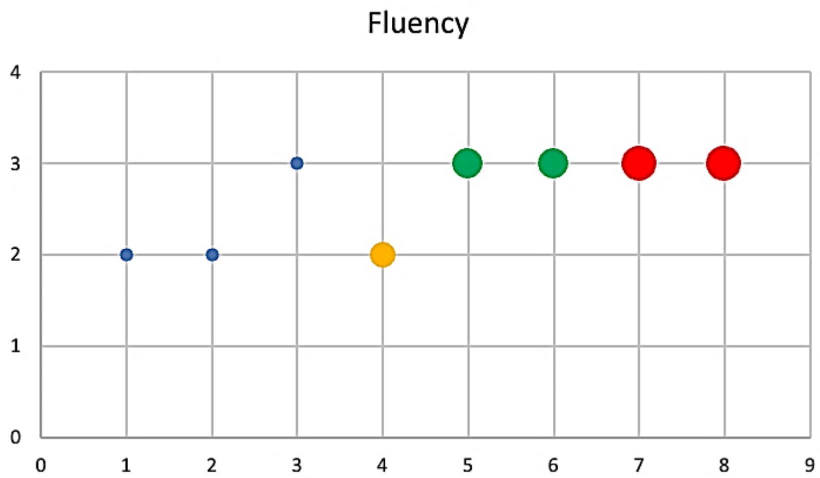

Figure 2. The distribution of students' fluency based on AI engagement

Based on Figure 2 above, it can be seen that subjects with high AI engagement (R1, R2) and moderate AI engagement (R3, R6) scored 3, indicating that the use of AI can optimize the idea generation process and the features of the developed learning media. A score of 3 indicates that the developed media provides varied and relevant examples, features, or activities to explain key concepts. This supports several findings that AI can enrich students' idea pools (Chen et al., 2025; Rahman, Almutairi, Mudhsh, & Al-Yafaei, 2025) thereby increasing fluency in generating alternative solutions. However, subjects with low AI engagement and not using AI demonstrated that fluency can still develop, albeit not optimally. Interestingly, R8, despite not using AI, still scored 3. These results show that fluency is not only influenced by external factors but also by individual abilities.

Flexibility

Flexibility is a person's ability to move between categories of ideas and generate varied solutions. In the context of this study, flexibility refers to students' ability to use multiple approaches, categories, or perspectives.

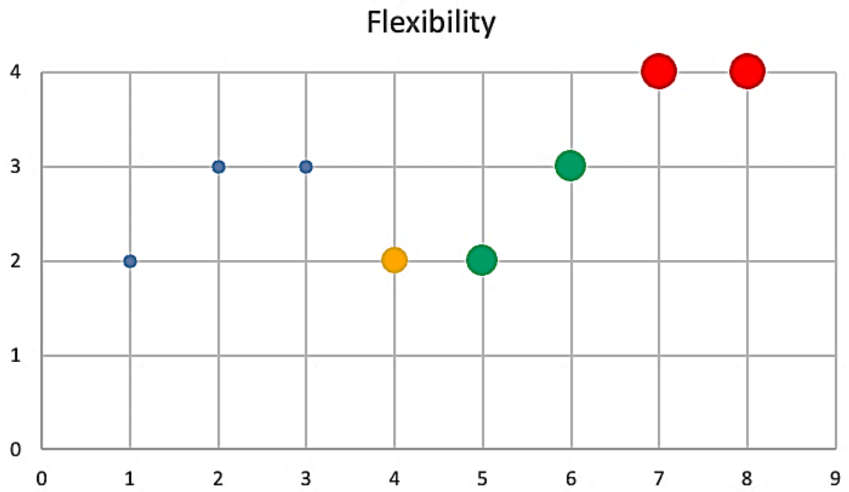

Figure 3. The distribution of students' flexibility based on AI engagement

Figure 3 above shows that subjects with high AI engagement both scored 4. A score of 4 indicates that the media was developed using an unexpected multi-representation approach, combining narrative, interactive, and audio, to facilitate understanding from multiple perspectives. This indicates that AI supports students' exploration of ideas in developing learning media. Several studies (Ashkinaze, Mendelsohn, Qiwei, Budak, & Gilbert, 2025; Choi, Hong, Park, Chung, & Kim, 2024; Meincke, Mollick, & Terwiesch, 2024) show that AI can expand the search space for ideas, thereby encouraging solution diversification. This may explain why students with high AI engagement scored the highest on the flexibility aspect.

However, students with moderate and low AI engagement, as well as those without AI, tended to score 3 or 2. This indicates that they used several types of representations, but not optimally. Some of the media they developed still used very conventional representations. Interestingly, two students who did not use AI (R5 and R8) scored 3. This suggests that flexibility can still develop without the aid of AI, especially if students actively explore various approaches.

Originality

Originality can be defined as the novelty, uniqueness, or degree of originality of an idea compared to existing ones (Runco & Jaeger, 2012). Data, as shown in Figure 4, indicate that students with high AI engagement tend to score higher than those in other categories. This indicates that AI can help students design unique learning media.

(Boden, 1998) stated that AI is capable of providing novel combinations of available information, thus expanding the possibilities for generating new ideas. However, limitations remain because AI tends to rely on existing patterns (Haidemariam & Gran, 2025; Lee et al., 2025; Liu & Chilton, 2022; Mosene, 2024).

Meanwhile, students with moderate and low AI involvement, as well as those without AI, tended to score 2, indicating that the learning media they created were slight modifications of existing media. Originality is a key indicator of creativity (Guilford & York StLouis San Francisco Toronto London Sydney, 1967; Ostermaier & Uhl, 2020;

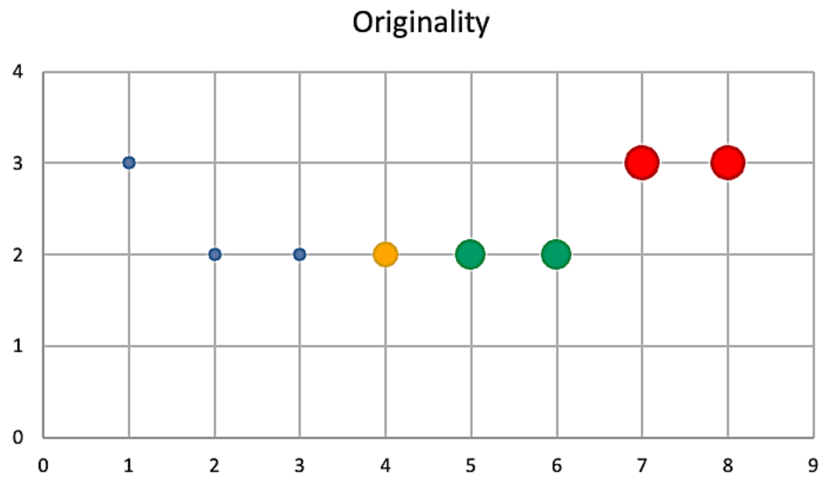

Figure 4. The distribution of students' originality based on AI involvement

Runco & Jaeger, 2012). Low scores on this originality aspect indicate that students are still at the conventional level of ideas.

Elaboration

Elaboration refers to the level of depth, detail, and refinement in the execution of ideas. Data such as those in Figure 5 show that students with high and moderate AI engagement scored better than the majority of students who used AI little or no all. This indicates that AI can develop initial ideas into more detailed and engaging learning media.

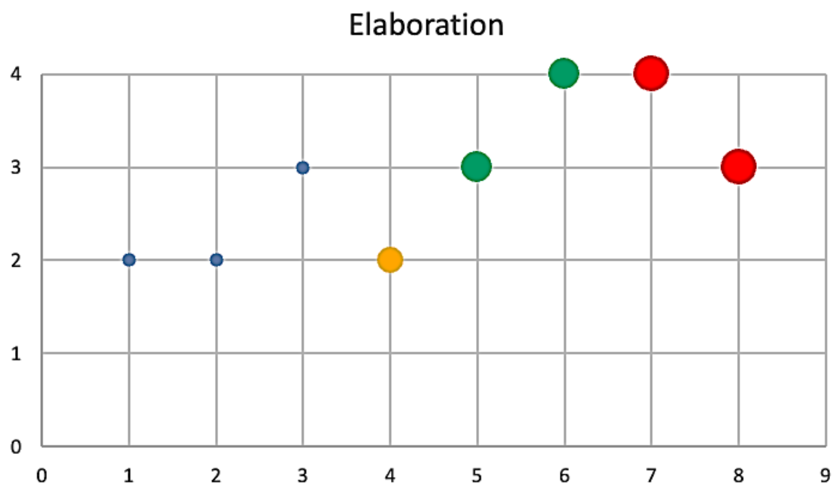

Figure 5. The distribution of students' elaboration based on AI engagement

Cross-Dimensional Analysis of Student Creativity in Developing Mathematics Learning Media

Cross-dimensional analysis of the research subjects shows that student creativity in developing mathematics learning media is the result of the interaction between the person dimension, the process dimension, the press dimension, and the product dimension. Students who have high internal motivation towards a particular thing, whether the tool or the type of media to be developed, tend to have a smooth and persistent creative thinking process and produce good learning media products. For example, R1 has a high motivation or interest in creating RPG game-based learning media, which encouraged him to create an educational game entitled The Lost Coordinates, which is considered interactive. The same condition was experienced by R2, who was explicitly interested in using Scratch and actualizing it into an interesting learning media entitled Detektif Pola.

However, not all students experience the same situation. High time pressure and technical difficulties can hinder the creation of optimal learning media for some students. This situation raises a fundamental question: why do some students struggle while others thrive under similar external pressures? It appears that external pressure is not the most influential factor. The key difference between them lies in how this pressure is mediated by the Person and Process dimensions.

R4 and R5 provide a clear picture of how students' internal dispositions directly shape their creative processes under pressure. R4 explicitly stated that her media creation was not driven by personal interest, but simply to fulfill course assignments. This task-oriented motivation resulted in a reactive, rather than proactive, creative process. She relied more heavily on feedback from lecturers or peers to overcome obstacles.

R5 demonstrated a similar sentiment. She chose to develop media on fractions due to its simplicity. Interestingly, she consciously rejected her colleagues' suggestions to add word problems to the practice problems included in the media she developed. R5 stated that adding word problems was too confusing, so she chose to stick with his plan. This decision, coupled with the pressure of assignments from other courses, illustrates a creative process that prioritizes completing assignments over conceptual exploration. For these two students, external pressure did not weaken their motivation; instead, it reinforced their existing mindset, which was focused on the task at hand. This led them to produce learning media that functioned well but lacked engagement.

Beyond individual dispositions, another critical environmental factor shaping the creative process was the students' interaction with technology. A particularly noteworthy finding is the dual role of technology, especially AI tools like ChatGPT, in reshaping the Press dimension. On the one hand, AI acted as a powerful agent in reducing traditional technical pressures. By serving as an on-demand problem solver, tools like ChatGPT lowered the barrier to entry for complex tasks such as coding, as mentioned by R1 and R2. This process of cognitive offloading appeared to free up students' mental resources, allowing them to shift their focus from logistical and technical hurdles to more critical pedagogical and creative considerations. In this sense, AI alleviated a significant source of pressure, enabling a deeper engagement with the core purpose of the media design task.

However, AI can also create new environmental pressures. First, the availability of powerful tools like ChatGPT can create expectations to produce more refined, complex, or sophisticated media, potentially shifting students' focus from the depth of pedagogy to the perfection of the media. "Then, ChatGPT suggested that if you do not use Construct, use G-Develop instead because it can produce outputs like web applications or mobile apps." (R1, Interview)

Second, effective use of AI requires strong digital literacy skills and the ability to create appropriate prompts, creating a potential gap between students who can effectively collaborate with AI and those who cannot. This introduces a new form of pressure related to technological fluency. "If there is an error in coding... I screenshot it, I send it to

ChatGPT... but the problem is that ChatGPT is sometimes a bit stupid..." (R1, Interview). “Well, there is a dead end, and I tried asking AI in ChatGPT; perplexity did not find an answer” (R7, Interview)

Finally, the ability of AI to generate endless alternatives could lead to a paradox of choice, where students feel overwhelmed by the possibilities, making it harder for them to commit to a single, well-developed creative path. "Then ChatGPT seemed to give me four options or something.." (R2, Interview). Therefore, our findings suggest that AI's role within the Press dimension is not merely additive, but transformative, alleviating old technical constraints while simultaneously creating new pressures related to creative standards and digital competence.

Overall, the person dimension underpins student creativity in the development of learning media. Students with intrinsic motivation, personal interests, and perseverance tend to be more resilient in facing challenges and are able to maximize environmental and technological support in creating mathematics learning media products. Meanwhile, the quality of the Product was closely influenced by the strength of the Process and Press dimensions, yet could not be fully realized without strong personal initiative.

This cross-dimensional analysis reinforces the understanding that creativity in education cannot be reduced to a single aspect; it is a holistic result of personality, internal processes, learning ecosystems, and tangible products. In other words, students who are able to integrate strengths across all four dimensions are more likely to produce educational media that is not only visually appealing and interactive, but also relevant, in-depth, and pedagogically valuable. The following illustration explains the relationship between the dimensions of creativity in this study.

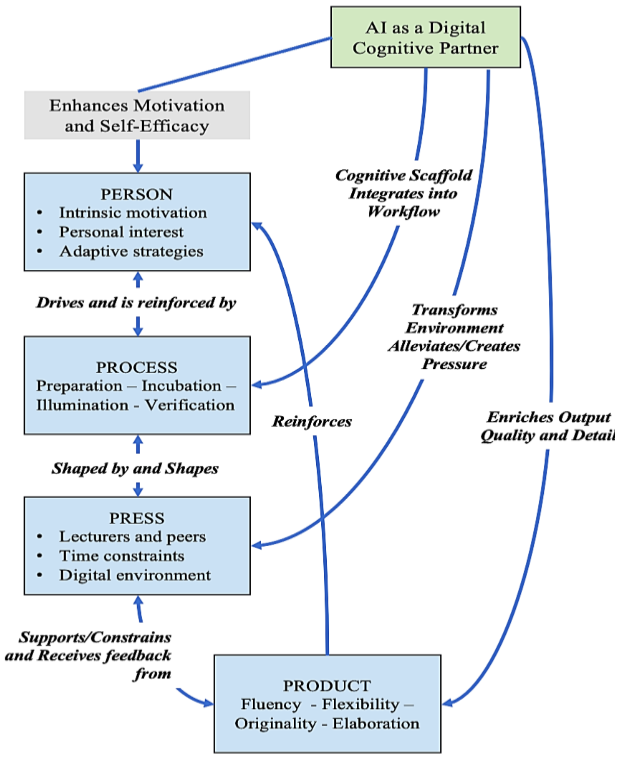

Figure 6. The interplay of the 4P dimensions mediated by AI as a digital cognitive partner

Figure 6 above displays the dynamic relationship between the four dimensions of creativity (Person, Press, Process, and Product) mediated by AI as a digital cognitive partner. AI's role is transformative, as the model demonstrates; it seamlessly integrates into the creative workflow, blurring the traditional boundaries between the individual and their environment (especially between Press and Process), and simultaneously introducing new forms of contextual pressure and cognitive support. Our results support 4P Rhodes' framework by demonstrating how each dimension continuously and simultaneously affects the others, creating a closely interconnected ecosystem rather than a linear sequence. In this model, the person dimension, consisting of internal motivation, personal interests, and adaptive strategies employed by students, acts as the primary driver of creativity. Students' creative thinking processes (preparation, incubation, illumination, and verification) are influenced by the press dimension. AI in Press can support creative thinking and technical execution, but can also introduce new pressures. Furthermore, the product dimension reflects the quality of the developed media (fluency, flexibility, originality, elaboration) while providing feedback to enhance self-efficacy and motivation.

Implications for Prospective Teacher Education

This study offers practical implications for teacher educators to foster creativity holistically, with interventions mapped onto the 4P framework. To strengthen the person dimension, educators need to cultivate intrinsic motivation by allowing freedom in topic selection and fostering an exploratory mindset that is resilient to failure. This must be supported by interventions in the process dimension, namely by explicitly teaching the stages of creative thinking and applying scaffolding so that students focus on pedagogical depth before becoming entangled in technical barriers. Within the press dimension, educators play a crucial role in managing the learning environment. They should frame technologies such as AI as collaborative partners, while consciously mitigating the new pressures they generate. Furthermore, the environment needs to be enriched with a structured culture of constructive feedback to encourage iteration. These implications converge in the product dimension, where assessment must shift from merely evaluating technical results toward a holistic evaluation that places significant weight on the originality of pedagogical ideas and the creative process itself, for example, through portfolio-based assessment. In this way, educators can create a balanced ecosystem for nurturing fully creative prospective teachers.

Limitations of the Study

This study has several weaknesses. First, the sample size is small and limited to the context of a mathematics learning media course conducted at a single university. Second, the results rely heavily on interview data and student reflective journals, which are subject to potential participant bias. Third, the findings regarding the role of AI in students' creativity should be viewed as preliminary. This is because rapid technological developments can change the dynamics and pressures of interactions in the future. Finally, as a qualitative study, this study successfully identified relationships between factors such as intrinsic motivation and learning media products, but failed to establish a causal relationship between the variables. This indicates the need for further research on a larger scale and with a mixed-method approach.

▪ CONCLUSION

This study concludes that the creativity of pre-service mathematics teachers in developing instructional media is not a single attribute but rather a dynamic ecosystem where personal motivation (Person) acts as the foundation that drives cognitive processes (Process), moderated by environmental support and pressures (Press), and ultimately manifests in the quality of the innovative product (Product). The findings reveal that intrinsic motivation and personal interest consistently serve as key predictors of students' ability to produce original and pedagogically deep media. Conversely, when motivation is merely pragmatic to fulfill a task, the creative process tends to become reactive and constrained, resulting in products that are functional yet less innovative, even when faced with similar external pressures.

Thus, the primary contribution of this research is how the 4P framework successfully uncovers the dynamic interplay between internal dispositions and external conditions that shape creative outcomes. This framework demonstrates that external pressures, such as time pressure, do not directly extinguish creativity. Instead, their impact is mediated by the strength of students' personal motivation (Person) and cognitive strategies (Process). Second, in the digital era, technologies like AI act as a transformative, double-edged facilitator. It can alleviate technical burdens while simultaneously creating new pressures related to standards of perfection and digital competence.

Looking forward, these findings call for a shift in pre-service teacher education, moving from merely teaching technical skills to cultivating a holistic, creative ecosystem. Educators must actively nurture intrinsic motivation (Person) by granting students autonomy, explicitly teach strategies for navigating ambiguous creative processes (Process), and wisely manage the learning environment (Press) by framing AI as a collaborative partner while mitigating its pressures. Therefore, product assessment must be conducted comprehensively, not only assessing the technical aspects of a product, such as the accuracy of software use, the quality of visual display, media functionality, and neatness, but also assessing the originality of the idea and the underlying creative process. Furthermore, given the limitations of this study, further research with a larger sample size and the use of mixed methods is needed to validate these findings and establish the relationship between motivation, AI use, and the quality of creativity of prospective teachers.

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Appendix A: Creativity Assessment Rubric for Learning Media Products

Dimension	Score 1	Score 2	Score 3	Score 4	Score (1-4)
Fluency (Flow of Ideas): The number of relevant ideas, examples, or features within the media.	The media presents only a single central idea or example with no variation.	The media presents a few examples or features, but they are repetitive or very similar to each other.	The media presents several varied and relevant examples, features, or activities to explain the main concept.	The media is rich with diverse ideas, examples, and features, demonstrating an in-depth exploration of how to present the concept.	
Flexibility (Flexibility of Approach): The ability to use various approaches, categories, or perspectives.	Uses only one type of representation (e.g., only text and standard mathematical symbols).	Uses two types of representation (e.g., symbols and visuals), but within a very conventional framework.	Effectively integrates multiple types of representation (e.g., visual, symbolic, and contextual).	Uses an unexpected multi-representational approach (e.g., combining narrative, kinesthetic-interactive elements, and music) to facilitate understanding from various viewpoints.	
Originality, novelty, uniqueness, or degree of authenticity of the idea compared to existing ones.	The analogy, context, or media format is very common, similar to what is typically found in standard textbooks or learning resources.	There is a slight modification of a common example, but the core idea is still very familiar.	Uses a fresh, uncommon analogy, context, or interaction mechanism that successfully captures attention.	Generates a completely new, innovative idea, metaphor, or presentation format that provides new insight into the mathematical concept.	

Elaboration (Detail & Refinement): The level of depth, detail, and refinement in the execution of the idea.	The execution of the idea is minimal, many details are overlooked, and the media appears unfinished or unpolished.	The media has adequate detail, but some parts feel disconnected or unrefined. Some functional aspects are not optimal.	The media is executed with rich detail, is well-structured, and all elements (visual, audio, navigation) function harmoniously and coherently.	Every detail is meticulously thought out. There is a high level of refinement in every aspect (e.g., user interface, feedback, user flow, aesthetics), creating a seamless and professional learning experience.