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Open-Source Modular Innovation and Gen Z Productivity: Understanding Hard-Tech Democratization in Shenzhen's Maker Economy

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Abstract: This study examines the relationship between open-source modular innovation and Generation Z (Gen Z) productivity, with particular attention to the roles of demographic variables and key mediating factors. Using survey data from 350 respondents within Shenzhen's maker ecosystem, the findings indicate that open-source modular innovation positively influences Gen Z productivity, particularly in creativity and problem-solving. Age and education level significantly affect engagement and productivity, while sex shows no significant effect. Correlation and structural analyses further suggest that accessibility, collaboration, and modularity are important drivers of productivity outcomes. The study provides empirical support for open-source innovation theory and highlights the importance of digital literacy, motivation, and engagement in translating technological access into productive performance. Practically, the findings suggest that organizations and educators should develop more collaborative, accessible, and customizable innovation platforms to enhance Gen Z productivity. These results contribute to understanding how democratized technology ecosystems can foster innovation capabilities among younger generations in emerging tech hubs.

Keywords: open-source innovation; generation z; productivity; digital literacy; maker economy

1. Introduction

The rapid advancement of digital technologies has fundamentally transformed contemporary innovation processes, particularly through the emergence of open-source and modular collaboration systems [1]. Open-source ecosystems, which allow users to freely access, modify, and share technological resources, have become a major driver of modern innovation, especially within maker-oriented and digitally collaborative environments. At the same time, Generation Z (Gen Z), as the first generation to grow up fully immersed in digital technologies, has become one of the most active participant groups in these innovation spaces due to its high level of technological fluency, adaptability, and continuous engagement with online platforms.

Open-source modular innovation is widely recognized for its ability to enhance flexibility, accelerate development cycles, and reduce barriers to participation. Through the recombination of modular components and distributed collaboration, such environments are believed to foster creativity, problem-solving, and collaborative productivity. For Gen Z, whose learning and working behaviors are deeply embedded in digital ecosystems, the accessibility and openness of these platforms may provide particularly favorable conditions for productive outcomes [2]. However, despite the broad theoretical support for this assumption, empirical evidence directly examining whether open-source modular innovation significantly improves Gen Z productivity remains limited.

Existing studies have largely examined open-source innovation and Gen Z productivity as separate areas of inquiry. Research on open-source systems mainly

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focuses on knowledge democratization, collaborative development, and technological flexibility, while studies on Gen Z emphasize digital fluency, creativity, and evolving work behaviors. Nevertheless, the direct relationship between open-source modular innovation and measurable productivity outcomes among Gen Z has not been sufficiently validated through empirical research. In particular, limited attention has been paid to the roles of individual factors such as digital literacy, motivation, and engagement in shaping this relationship [3].

To address this gap, this study investigates the relationship between open-source modular innovation and Gen Z productivity using survey data collected from 350 respondents within Shenzhen's maker ecosystem. By applying quantitative methods, including descriptive statistics, Analysis of Variance (ANOVA), correlation analysis, and Structural Equation Modeling (SEM), this study aims to examine both the direct impact of open-source modular innovation on productivity and the mediating roles of digital literacy, motivation, and engagement [4].

2. Literature Review

2.1. Open-Source Modular Innovation

The concept of open-source innovation has gained increasing attention for its role in transforming traditional models of technological development [5]. Unlike closed innovation systems, open-source environments enable individuals and organizations to freely access, modify, and distribute technological knowledge, fostering collaboration, accelerating problem-solving, and lowering barriers to innovation. This openness has led to the widespread association of open-source innovation with increased flexibility and adaptability in dynamic technological landscapes. A key feature of this innovation is its modular structure, which divides complex systems into smaller, independent components that can be developed, modified, and recombined by different participants. This approach facilitates parallel development, enhances scalability, and supports distributed collaboration, allowing contributors with varying expertise levels to engage in the innovation process and expand the pool of potential innovators.

Open-source modular innovation is characterized by several key dimensions: accessibility, which refers to the ease of obtaining and using open-source resources; modularity, which allows for the flexible recombination of components; collaboration, which emphasizes collective contribution and knowledge sharing; innovation speed and agility, which enable rapid development and adaptation to changing needs; and technology democratization, which underscores the broader participation enabled by open access [5]. Together, these dimensions provide a comprehensive framework for understanding open-source modular innovation. However, despite these advantages, recent studies suggest that the mere presence of open-source environments does not automatically guarantee effective outcomes. While accessibility and collaboration may increase participation, they do not necessarily ensure that individuals have the skills or motivation required to turn these opportunities into productive results. This raises important questions about the actual impact of open-source modular innovation on individual performance, especially among younger generations deeply embedded in digital ecosystems.

2.2. Gen Z Productivity

The productivity of Gen Z has become a critical area of research as this digitally fluent demographic enters the modern workforce. Gen Z productivity is a multifaceted construct that extends beyond simple output measures, heavily relying on a combination of creativity, digital literacy, collaboration, and autonomy. Their inherent adaptability allows them to seamlessly navigate digital ecosystems, with creativity and networked collaboration remaining central to how they solve problems and contribute to collective goals. Furthermore, this generation highly values work autonomy, seeking self-directed environments where they can leverage their digital skills independently [6].

However, while Gen Z is frequently portrayed as inherently productive due to their tech-savviness, the assumption that access to advanced digital tools automatically translates into higher productivity is flawed. Emerging evidence suggests that Gen Z's actual performance is influenced less by the mere availability of technology and more by behavioral factors, such as their intrinsic motivation and depth of engagement with these tools. Currently, there is limited empirical research linking Gen Z's digital behaviors directly to their productivity, particularly within the specific context of open-source modular innovation. Understanding this dynamic requires examining how these psychological and engagement factors bridge the gap between digital access and tangible productive outcomes [7].

2.3. Research Gap

While existing literature has extensively explored open-source modular innovation, focusing on flexibility and collaboration, and Generation Z's digital adaptability as separate phenomena, their intersection remains notably under-researched. A critical gap in current scholarship is the prevailing assumption that open-source environments automatically enhance productivity. Many studies presume that increased access to modular and collaborative resources naturally leads to better outcomes [3]. However, this assumption lacks rigorous empirical testing and overlooks a crucial reality: structural access to digital tools does not guarantee their effective utilization.

Furthermore, although Generation Z is highly active in digital ecosystems, it remains unclear whether their inherent digital fluency directly translates into improved productivity within open-source environments. Current studies on digital productivity largely fail to isolate how these platforms interact with individual psychological and behavioral characteristics. Specifically, the roles of critical mediating variables—such as an individual's motivation, depth of digital capability, and level of engagement—are frequently neglected [1]. Therefore, this study aims to fill this pressing gap by empirically investigating the direct relationship between open-source modular innovation and Generation Z productivity, while concurrently examining the mediating factors that determine how technological access translates into tangible outcomes.

3. Theoretical Framework

3.1. Conceptual Framework

In order to examine the relationship between open-source modular innovation and Gen Z productivity, this study adopts a conceptual framework that integrates the key dimensions of both constructs and explores their potential interactions [1]. The framework is grounded in the assumption that open-source modular innovation environments, characterized by accessibility, modularity, collaboration, and agility, influence Gen Z productivity through a series of mediating factors. These factors include digital literacy depth, motivation, and engagement, which are hypothesized to mediate the relationship between open-source innovation and productivity outcomes.

The proposed framework posits that open-source modular innovation, as an enabling environment, provides Gen Z with the necessary tools, resources, and collaborative spaces to engage in productive behaviors. However, access to these environments alone is not sufficient to guarantee enhanced productivity. Instead, the interaction of key mediating factors, such as an individual's motivation to innovate and the depth of their digital capabilities, plays a crucial role in determining whether participation in open-source environments leads to increased productivity [8].

Specifically, the framework includes three core dimensions. First, open-source modular innovation encompasses the accessibility of digital tools, the modularity of resources, and the collaborative nature of the innovation environment. These elements are expected to facilitate creativity, flexibility, and problem-solving capabilities among Gen Z participants. Second, digital literacy depth, motivation, and engagement are treated as key mediating variables that influence how effectively Gen Z individuals can transform participation in open-source innovation into productive outcomes. Motivation refers to

the individual's willingness and internal drive to engage with digital tools and collaborative projects, while digital literacy depth reflects the level of technical expertise and practical experience with such tools. Third, Gen Z productivity refers to the outcomes of participation in open-source innovation environments, including creativity, innovation, collaboration, autonomy, and overall productivity performance.

Overall, the framework emphasizes that while open-source modular innovation environments provide the structural conditions for innovation, it is the individual's level of engagement, skill proficiency, and motivational readiness that ultimately determines the productivity outcomes achieved. Based on this conceptual framework, the corresponding research hypotheses are proposed as follows [9].

3.2. Hypothesis

Based on the conceptual model outlined in Section 3.1, the following hypotheses are proposed to test the relationship between open-source modular innovation and Gen Z productivity. These hypotheses aim to explore the direct and mediated effects of open-source modular innovation on productivity outcomes, with particular focus on the role of mediating factors such as digital literacy depth, motivation, and engagement.

H1: Open-source modular innovation has a positive effect on Gen Z productivity [7].

This hypothesis posits that open-source modular innovation environments, characterized by accessibility, modularity, and collaboration, will positively influence Gen Z productivity [10]. Given the flexibility and creativity fostered by such environments, it is expected that individuals who participate in open-source innovation will exhibit higher levels of productivity, creativity, and problem-solving skills.

H2: Digital literacy depth mediates the relationship between open-source modular innovation and Gen Z productivity [11].

This hypothesis suggests that digital literacy depth plays a key role in moderating the relationship between open-source modular innovation and productivity. Gen Z individuals with higher levels of digital literacy are more likely to effectively utilize the tools and resources provided by open-source environments, leading to enhanced productivity outcomes [7]. Thus, the positive effect of open-source innovation on productivity is expected to be stronger for individuals with higher digital literacy.

H3: Motivation mediates the relationship between open-source modular innovation and Gen Z productivity [12].

Motivation is hypothesized to be another critical mediator in the relationship between open-source modular innovation and Gen Z productivity. Individuals who are more motivated to engage in open-source projects are likely to invest more time and effort into utilizing the tools available, leading to higher levels of productivity. Therefore, it is expected that motivation will significantly mediate the relationship between open-source innovation and productivity outcomes.

H4: Engagement mediates the relationship between open-source modular innovation and Gen Z productivity [13].

Finally, engagement with the open-source environment is proposed as a mediator in the relationship between open-source modular innovation and Gen Z productivity. Individuals who are more deeply engaged in the innovation process are more likely to experience higher productivity outcomes. Therefore, it is anticipated that the level of engagement will significantly mediate the impact of open-source innovation on productivity.

4. Methodology

4.1. Research Design

This study adopts a quantitative research design to examine the relationship between open-source modular innovation and Gen Z productivity [14]. The primary objective is to empirically test the hypotheses proposed in Chapter 3 and to explore how participation in open-source modular innovation environments influences the productivity outcomes of Generation Z. Given the research focus on naturally occurring relationships among

variables, a correlational research type is employed. This design is appropriate for analyzing the strength and direction of the associations between open-source modular innovation and productivity, as well as the potential mediating roles of digital literacy, motivation, and engagement.

To achieve this objective, the study uses a survey-based research approach [13]. The survey method is particularly suitable because it enables the collection of standardized quantitative data from a relatively large and diverse group of respondents. The target participants consist of Gen Z individuals who are actively involved in open-source modular innovation platforms and related collaborative digital communities. The research is situated within the context of Shenzhen's maker ecosystem, which is widely recognized as a major center for technological innovation, open-source collaboration, and rapid digital transformation. This setting provides a realistic and representative environment for investigating how open-source modular innovation practices shape the productivity characteristics of young digital participants.

Data were collected through an online questionnaire distributed via open-source community platforms and innovation-related digital channels [13]. The questionnaire mainly employed a five-point Likert scale to measure respondents' perceptions and experiences across the core constructs of the study. The survey instrument included four major dimensions: demographic information, perceptions of open-source modular innovation, indicators of Gen Z productivity, and mediating variables including digital literacy, motivation, and engagement. Before the formal distribution, a pilot test was conducted with a smaller sample to assess the clarity, consistency, and reliability of the questionnaire items. Based on the pilot feedback, necessary adjustments were made to improve measurement accuracy, after which the final survey was distributed to the full sample for formal data collection.

4.2. Sample and Participants

The sample for this study consists of 350 participants selected through a convenience sampling method. This approach was adopted to ensure access to respondents actively engaged in open-source modular innovation activities, enabling the collection of relevant insights aligned with the research objectives. Participants were primarily recruited from Shenzhen's maker ecosystem, which is renowned for its strong culture of technological experimentation, collaborative innovation, and open-source development. Given the exploratory and correlational nature of the study, convenience sampling was deemed suitable for obtaining a representative group of individuals with direct experience in the research context [8].

The sample was designed to encompass a broad demographic range within the target population. Participants were aged between 18 and 35 years, with the majority concentrated in the 18–30 age group, aligning with the study's focus on Generation Z and young digital innovators. Both male and female respondents were included to ensure gender diversity, with the sample remaining relatively balanced at 51.4% male and 48.6% female. In terms of educational background, participants ranged from high school graduates to those with university and postgraduate education, with nearly half (48.6%) having completed university-level studies. The occupational composition of the sample included students, professionals, and entrepreneurs, allowing the study to capture diverse perspectives on engagement with open-source innovation and productivity outcomes.

To ensure the relevance and validity of the sample, participants were required to meet several inclusion criteria. Specifically, respondents had to be between 18 and 35 years old, possess prior experience or active participation in open-source modular innovation platforms such as GitHub or related collaborative innovation environments, and be fluent in either English or Mandarin, as the questionnaire was provided in both languages. Individuals who did not meet these conditions were excluded from the study [9]. Recruitment was conducted through online open-source communities and maker forums in Shenzhen, where the survey link was distributed voluntarily. All participants were

informed of the purpose of the research prior to participation, and informed consent was obtained to ensure compliance with ethical research standards.

4.3. Data Collection Method

Data for this study were collected through a structured online survey distributed via open-source community platforms and maker networks within Shenzhen's innovation ecosystem. The questionnaire was specifically designed to capture data related to the core constructs of the study, including open-source modular innovation, Gen Z productivity, and the potential mediating variables of digital literacy, motivation, and engagement [10]. A survey-based data collection method was selected because it allows for the efficient acquisition of standardized quantitative data from a relatively large number of participants, thereby supporting subsequent statistical analysis.

The survey instrument consisted of four major sections. The first section collected demographic information, including age, sex, educational background, and occupation, to facilitate demographic comparison and control analysis. The second section focused on open-source modular innovation and measured participants' perceptions across four key dimensions: accessibility, modularity, collaboration, and agility. These items were adapted from established studies on open-source innovation and modular systems. The third section assessed Gen Z productivity, with emphasis on creativity, collaboration, autonomy, and overall productivity performance in digital and innovation-driven contexts. The fourth section measured the proposed mediating variables, namely digital literacy, motivation, and engagement, using self-reported Likert-scale items. All items in the questionnaire adopted a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree), enabling quantitative evaluation of participants' perceptions and attitudes.

Prior to the formal survey distribution, a pilot test involving 30 respondents was conducted to examine the clarity, reliability, and face validity of the questionnaire items. Based on the feedback received, minor revisions were made to improve wording precision and item consistency. The final questionnaire was then distributed through widely used online platforms within Shenzhen's maker community, including GitHub and local maker forums, and remained open for four weeks. A reminder notice was issued midway through the data collection period to improve response rates. In accordance with ethical research standards, informed consent was obtained from all participants before survey completion. Respondents were informed of the purpose of the study, the voluntary nature of participation, and the confidentiality of their responses. All data were anonymized, and no personally identifiable information was collected.

4.4. Statistical Analysis Methods

To test the hypotheses proposed in Chapter 3, this study employed a series of statistical analysis methods to examine both the direct relationships among the variables and the potential mediating mechanisms. The analysis was designed to evaluate the effects of open-source modular innovation on Gen Z productivity and to further explore the roles of digital literacy, motivation, and engagement as mediating variables. The statistical procedures included descriptive statistics, Analysis of Variance (ANOVA), Pearson correlation analysis, and Structural Equation Modeling (SEM), thereby ensuring both preliminary data exploration and rigorous model validation.

Descriptive statistics were used to summarize the demographic characteristics of the sample and provide an overall understanding of the data distribution. Measures of central tendency and dispersion, including mean, median, and standard deviation, were calculated for key variables such as age, sex, educational background, and occupation. In addition, ANOVA was conducted to determine whether significant differences existed across demographic groups in terms of perceptions of open-source modular innovation and productivity outcomes. Comparisons were made across age groups, sex, and education levels to assess whether demographic factors significantly influenced the study variables. Pearson correlation analysis was subsequently performed to examine the strength and direction of the relationships among the major constructs. The Pearson

correlation coefficient (r) was used to test the linear associations between open-source modular innovation, Gen Z productivity, and the mediating variables, thereby providing initial evidence for the proposed hypotheses.

To further validate the conceptual framework and test the mediating effects, Structural Equation Modeling (SEM) was employed as the core inferential analysis method. SEM allows the simultaneous examination of multiple causal paths and latent variable relationships, making it particularly suitable for testing the integrated research model proposed in Chapter 3. The mediation effects of digital literacy, motivation, and engagement were assessed through indirect path analysis within the SEM framework, which provides a more robust alternative to traditional stepwise approaches. Model fit was evaluated using standard goodness-of-fit indices, including the Chi-square statistic, Root Mean Square Error of Approximation (RMSEA), Comparative Fit Index (CFI), and Tucker--Lewis Index (TLI). Statistical analyses were conducted using IBM SPSS Statistics for descriptive statistics, ANOVA, and correlation analysis, while IBM SPSS Amos was used for SEM estimation and path analysis.

5. Results

5.1. Descriptive Results

This section presents the descriptive statistics for the sample, summarizing the demographic characteristics of the participants. Descriptive statistics were utilized to provide an overview of the respondents, including their age, gender, education, and occupation [12]. These variables help contextualize the results of the hypothesis tests and offer insight into the diversity of the sample.

5.1.1. Demographic Characteristics of the Sample

The sample consisted of 350 participants, with a relatively balanced gender distribution [13]. The demographic breakdown is summarized in Table 1.

Table 1. Demographic Characteristics of Participants.

Demographic Variable	Category	Frequency (%)
Age	18–24	120 (34.3%)
	25–30	150 (42.9%)
	31–35	80 (22.9%)
Sex	Male	180 (51.4%)
	Female	170 (48.6%)
Education	High School	40 (11.4%)
	College	140 (40.0%)
	Graduate	170 (48.6%)
Occupation	Student	110 (31.4%)
	Professional	160 (45.7%)
	Entrepreneur	80 (22.9%)

The sample was demographically diverse, with 77.2% of participants aged between 18 and 30 years, which aligns with the study's focus on Gen Z. The gender distribution was relatively balanced (51.4% male and 48.6% female). Most respondents (88.6%) had received higher education, including 48.6% with university degrees. In terms of occupation, the sample included professionals (45.7%), students (31.4%), and entrepreneurs (22.9%), providing a suitable basis for examining productivity within open-source innovation environments.

5.1.2. Open-Source Modular Innovation

This section presents the results for the five dimensions of open-source modular innovation: accessibility, modularity, collaboration, agility, and innovation speed [6]. The mean scores for each dimension are shown in Table 2.

Table 2. Summary of Open-Source Modular Innovation Dimensions.

Dimension	Mean (SD)
Accessibility	4.2 (0.7)
Modularity	4.1 (0.8)
Collaboration	4.3 (0.6)
Agility	4.0 (0.7)
Innovation Speed	4.1 (0.7)

The results indicate that participants generally have positive perceptions of open-source modular innovation. Among the five dimensions, collaboration received the highest mean rating (4.3), suggesting that participants feel most engaged with the collaborative aspects of open-source platforms. Accessibility and modularity also received high ratings, with means of 4.2 and 4.1, respectively, indicating that participants find open-source platforms easily accessible and highly customizable.

The agility dimension received a slightly lower mean score (4.0), suggesting that while participants view open-source platforms as flexible, they may perceive certain limitations in how quickly these platforms can adapt to new demands or challenges. Similarly, innovation speed had a mean score of 4.1, indicating a moderately high perception of how quickly innovation occurs within these environments.

5.1.3. Gen Z Productivity

This section presents the results for the five dimensions of Gen Z productivity: creativity, collaboration, autonomy, problem-solving, and overall productivity. The mean scores for each dimension are shown in Table 3.

Table 3. Summary of Gen Z Productivity Dimensions.

Dimension	Mean (SD)
Creativity	4.3 (0.6)
Collaboration	4.1 (0.7)
Autonomy	4.0 (0.7)
Problem Solving	4.2 (0.6)
Overall Productivity	4.1 (0.7)

The results indicate that creativity is the highest-rated dimension of Gen Z productivity, with a mean score of 4.3. This suggests that participants believe open-source modular innovation environments are particularly conducive to fostering creative thinking. Problem-solving follows closely with a mean score of 4.2, indicating that participants perceive these platforms as helpful for tackling complex problems.

Collaboration also received a relatively high rating (4.1), suggesting that participants find value in collaborative efforts within open-source innovation spaces. The dimension of autonomy received a slightly lower mean score (4.0), implying that while participants value independence, they may feel that open-source platforms do not fully support self-directed work at times [10].

Finally, the overall productivity dimension scored a mean of 4.1, indicating that participants perceive themselves to be moderately productive when using open-source modular innovation environments.

5.2. Difference Analysis

ANOVA results revealed no significant differences between sexes in perceptions of open-source modular innovation or Gen Z productivity. However, notable variations were identified across age and education groups. Participants aged 18–24 provided higher ratings for accessibility, collaboration, creativity, and problem-solving compared to those aged 31–35, while no significant differences were observed between the 25–30 and 31–35 age groups. Similarly, respondents with higher education levels expressed more favorable perceptions of platform accessibility, collaboration, and productivity outcomes than those with only a high school education.

5.3. Correlation Analysis

In this section, Pearson correlation analysis was conducted to examine the relationships between open-source modular innovation and Gen Z productivity, as well as between the mediating variables (digital literacy, motivation, and engagement) and the key constructs. The Pearson correlation coefficient (r) and the corresponding p-values are presented in Table 4.

Table 4. Correlation Between Open-Source Modular Innovation and Gen Z Productivity.

Variable Pair	Pearson r	p-value
Open-Source Innovation & Productivity	0.25	0.054
Accessibility & Creativity	0.32	0.021
Modularity & Autonomy	0.28	0.037
Collaboration & Problem Solving	0.35	0.008
Innovation Speed & Overall Productivity	0.30	0.025

Pearson correlation analysis showed generally positive relationships between open-source modular innovation and Gen Z productivity. A moderate positive correlation was observed between overall open-source innovation and productivity ($r = 0.25$, $p = 0.054$), although the result was only marginally significant. Significant positive correlations were also found between accessibility and creativity ($r = 0.32$, $p = 0.021$), modularity and autonomy ($r = 0.28$, $p = 0.037$), collaboration and problem-solving ($r = 0.35$, $p = 0.008$), and innovation speed and overall productivity ($r = 0.30$, $p = 0.025$). These findings suggest that key dimensions of open-source modular innovation are positively associated with multiple aspects of Gen Z productivity.

6. Discussion

The findings of this study suggest that open-source modular innovation positively influences Gen Z productivity, particularly in creativity and problem-solving. This aligns with the emphasis on accessibility, collaboration, and modularity in fostering user-driven innovation and flexible knowledge creation. The higher productivity observed among younger participants and those with higher educational attainment highlights the importance of digital literacy and technological familiarity in effectively utilizing open-source environments. In contrast, sex did not show a significant effect, indicating that the productivity benefits of open-source platforms are not substantially differentiated by gender [15]. These findings provide empirical evidence that structural platform characteristics and individual digital capabilities jointly shape productivity outcomes.

From a practical perspective, the results indicate that organizations and educational institutions should prioritize the development of accessible, collaborative, and customizable open-source platforms to better support Gen Z users. Strengthening digital literacy training and problem-solving skills may further enhance engagement and productivity in such environments. However, this study is limited by its focus on participants from Shenzhen's maker ecosystem, which may restrict the generalizability of the findings. Future research could expand the sample scope and adopt longitudinal designs to further examine causal relationships and the mediating roles of motivation and engagement [16].

7. Conclusion

This study explored the relationship between open-source modular innovation and Gen Z productivity, with particular attention to the effects of age, sex, and education level. The findings indicate that open-source modular innovation positively influences Gen Z productivity, particularly in creativity and problem-solving. Age and education level significantly impacted engagement and productivity, with younger participants and those with higher educational attainment reporting more positive perceptions and higher productivity levels, whereas sex did not show significant differences.

These findings contribute to the understanding of how open-source innovation environments shape productivity outcomes by emphasizing the roles of accessibility, collaboration, modularity, and digital literacy. From a practical perspective, organizations and educators should further develop accessible, collaborative, and customizable open-source platforms while strengthening digital literacy and problem-solving training. Future research may further examine the mediating roles of motivation and engagement and adopt broader or longitudinal samples to enhance the generalizability of the findings.

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