ENHANCING CHEMISTRY TEACHERS' READINESS TO DEVELOP 3D LEARNING MEDIA THROUGH FABLAB-BASED TRAINING IN BANDAR LAMPUNG, INDONESIA

M. SETYARINI[1*], Bayu SAPUTRA[2], Ni Putu Rahma AGUSTINA[3], Mohammad AHDIAT[4], Ila ROSILAWATI[5]
[1-5]***Faculty Teacher Training and Education, Universitas Lampung***
Email corresponding author: m.setyarini@fkip.unila.ac.id

ABSTRACT

The development of digital fabrication technology provides opportunities for teachers to develop innovative and tangible learning media for chemistry education. However, many chemistry teachers still have limited experience in designing and producing three-dimensional (3D) learning media using digital fabrication technology. This community service program aimed to improve chemistry teachers' understanding of FabLab, develop their skills in designing 3D learning media, and provide practical experience in producing 3D-printed learning media for chemistry instruction. The program involved 23 chemistry teachers in Bandar Lampung and was conducted through informative-participative training, including FabLab introduction, Tinkercad practice, mentoring, 3D printing, and reflection. Data were obtained from participants' reflective responses and interviews and analyzed using Quantitative Content Analysis (QCA). The findings showed that participants gained new understanding of FabLab and digital fabrication, developed basic skills in 3D design, experienced the process of producing 3D learning media, and recognized the potential of 3D media to support chemistry learning. The results indicate that FabLab-based training provides an integrated professional development experience that connects technological knowledge, practical skills, and pedagogical application in chemistry education.

Keywords: FabLab, Chemistry Teachers, 3D Printing, Learning Media, Teacher Professional Development.

1. INTRODUCTION

The development of digital technology has created new opportunities to enhance learning through the development of innovative and interactive media. In chemistry education, this need is particularly important because many concepts involve molecular structures, spatial arrangements, and submicroscopic phenomena that are difficult to represent through conventional two-dimensional media. Three-dimensional (3D) media can provide more concrete representations and support the visualization of chemical structures from different perspectives (Pernaa & Wiedmer, 2020; Pinger et al., 2020). Research on the use of 3D printing in education has also shown that this technology has been used to produce models and artifacts that support the learning process, although its implementation still requires further development (Ford & Minshall, 2019).

The use of 3D media is also relevant to chemistry concepts that require spatial visualization. For example, 3D printing technology has been applied in learning the Valence Shell Electron Pair Repulsion (VSEPR) theory to help students understand the three-dimensional shapes of molecules (Dean et al., 2016). Other studies have shown that 3D printing can be used to produce devices and models that support chemistry learning, including experimental equipment that can be utilized in educational contexts (Renner & Griesbeck, 2020; Maršálek et al., 2025).

One technology that supports the development of 3D learning media is the *Fabrication Laboratory* (FabLab). FabLab integrates digital design and fabrication, enabling digital ideas or designs to be developed into physical products. In educational contexts, digital fabrication environments can support activities involving designing, making, testing, and improving products directly. This approach is consistent with the characteristics of *maker education*, which places *design and making* as important components of the learning experience (Sheridan et al., 2014). FabLab also has the potential to serve as an environment for developing technological and digital fabrication skills through access to various digital manufacturing technologies (García-Ruiz & Lena-Acebo, 2022).

However, the utilization of FabLab in chemistry education still faces limitations in terms of teachers' understanding and competencies. Khefrianti et al. (2024) found that the chemistry teachers investigated had limited understanding of FabLab; even some teachers who were familiar with 3D printing did not have a comprehensive understanding of the FabLab concept. The study also indicated that the availability of 3D printing facilities in schools was not necessarily accompanied by optimal utilization due to limitations in technological proficiency.

Meanwhile, an analysis of the partner's conditions in the field indicated that high school chemistry teachers in Bandar Lampung still face limitations in visualizing abstract chemistry concepts and developing 3D-based learning media. The utilization of 3D design and printing technologies through FabLAB has also not been optimal due to limitations in knowledge, skills, and access to continuous training and mentoring. These conditions indicate the need for practical FabLAB-based media development training to support the improvement of teachers' competencies in developing 3D learning media.

In response to these conditions, teacher professional development needs to integrate technological knowledge, practical experience, and pedagogical considerations. This is consistent with the *Technological Pedagogical Content Knowledge* (TPACK) framework, which emphasizes the relationship among technological, pedagogical, and content knowledge in the integration of educational technology (Mishra & Koehler, 2006). Research on TPACK also indicates that technology integration in learning needs to consider the relationship between technological knowledge, pedagogy, and teachers' disciplinary expertise (Saputra & Chaeruman, 2022).

In response to these conditions, the Department of Chemistry Education, Universitas Lampung, conducted a FabLab-based training program for chemistry teachers in Bandar Lampung. The training integrated an introduction to FabLab, Tinkercad-based 3D design, hands-on 3D printing practice, mentoring, and reflection. Unlike activities that focus solely on introducing technology, this program provided teachers with direct experience ranging from designing to producing 3D learning media, as well as considering its potential application in chemistry learning.

Therefore, this community service program aimed to: (1) improve teachers' understanding of FabLab and digital fabrication, (2) develop teachers' skills in designing 3D learning media, and (3) provide practical experience in producing and considering the implementation of 3D-printing-based media in chemistry learning. Participants' reflective responses and interviews were analyzed using *Quantitative Content Analysis* (QCA) to identify the learning experiences and readiness that emerged following the training (Coe & Scacco, 2017).

2. METHOD

Community Service Design

This This community service program employed an informative-participatory training approach that integrated theoretical instruction, demonstrations, hands-on practice, mentoring, and reflection. This approach was designed to address the needs of chemistry teachers in Bandar Lampung in utilizing digital fabrication technology to develop three-dimensional (3D) learning media. The training design combined theoretical and practical activities. In detail, the implementation consisted of four main stages: (1) introduction to FabLab and digital fabrication, (2) 3D modeling using Tinkercad, (3) hands-on 3D printing practice and product development, and (4) reflection and evaluation. The overall sequence of the training activities is presented in Figure 1.

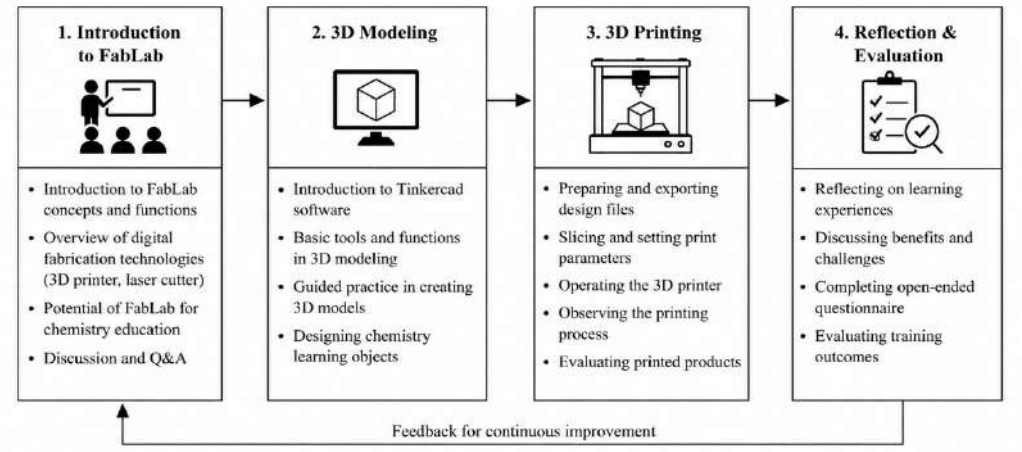


Figure 1. Stages of FabLab-Based 3D Learning Media Training

This sequence allowed participants to experience the complete basic workflow of digital fabrication, from understanding the technology and developing a digital design to producing a physical object and considering its application in chemistry learning.

Participants and Training Implementation

The participants were 23 chemistry teachers affiliated with the Chemistry Teachers' Working Group (MGMP Kimia) in Bandar Lampung. The MGMP served as the community service partner and supported participant coordination and implementation of the training. The activity was conducted at the FabLab Corner, Department of PMIPA, Faculty of Teacher Training and Education, Universitas Lampung. The training utilized computers, Tinkercad, 3D printers, printing filament, laser cutting equipment, and supporting materials. The implementation began with an introduction to FabLab, digital fabrication, and the potential application of 3D media in chemistry learning. Participants then practiced basic 3D modeling using Tinkercad, including manipulating geometric objects and developing simple chemistry-related learning objects. The next stage involved the 3D printing process, including preparing design files, slicing, operating the printer, and observing the resulting products. The activity concluded with reflection, discussion, and evaluation of the participants' experiences and potential classroom applications.

Data Collection

Data were collected from open-ended reflective responses and participant interviews conducted at the end of the training. The responses addressed participants' learning experiences, competencies gained, perceived benefits and classroom applications of 3D-printed media, and motivation for future implementation. The responses served as the primary data and were analyzed using Quantitative Content Analysis (QCA). Original photographs of the training activities, including FabLab introduction, Tinkercad practice, mentoring, 3D printing, and products, were used as supporting documentation of the implementation.

Data Analysis

Participants' reflective responses were analyzed using Quantitative Content Analysis (QCA), which systematically categorizes textual responses and quantifies the frequency of identified categories (Coe & Scacco, 2017). The analysis was conducted through four steps: (1) reading and familiarizing with participants' responses, (2) identifying meaningful statements relevant to the training objectives, (3) coding and grouping similar responses into indicators, and (4) calculating the frequency and percentage of participants expressing each indicator. This procedure enabled the qualitative responses to be summarized quantitatively while retaining their connection to participants' experiences.

The coding categories were developed deductively based on the objectives and activities of the training, covering knowledge of FabLab, technical skills in 3D design and fabrication, pedagogical understanding, perceived usefulness and classroom implementation, and participants' motivation and confidence in using 3D learning media. Each response was coded when it contained explicit evidence of the corresponding indicator. The frequency of each indicator was then calculated based on the number of participants mentioning the indicator. The percentage of participants for each indicator was calculated using the following formula:

$$P = \frac{f}{N} x100\%$$

Where P is the percentage, f is the frequency of participants demonstrating the indicator, and N is the total number of participants (N=23). The indicators were subsequently synthesized into five dimensions: cognitive, technical, pedagogical, implementation, and psychological readiness. The resulting percentages were interpreted descriptively to show the extent to which the training outcomes were reflected in participants' responses.

Alignment of Evaluation with Community Service Objectives

In this community service program, the evaluation focused on the three main outcomes targeted by the training.

Table 1. Alignment of training objectives and evaluation evidence

Community Service Objective	Training Activity	Supporting Evidence
Improve teachers' understanding of FabLab	FabLab introduction, digital fabrication presentation, discussion, and demonstration	Participants' descriptions of knowledge and understanding gained
Improve teachers' skills in designing 3D learning media	Tinkercad demonstration, guided practice, and mentoring	Participants' descriptions of technical skills and design experiences, supported by activity documentation
Improve teachers' ability to produce 3D-printed learning media	3D printing practice, mentoring, and product evaluation	Participants' descriptions of production experience and potential classroom use, supported by documentation of printing activities and products

The table above serves as a guide for achieving the training objectives, implementing the training activities, and evaluating the outcomes, which are presented in the Results and Discussion section.

3. RESULTS AND DISCUSSION

Implementation of the FabLab-Based Training

The FabLab-based training was implemented through a sequence of activities consisting of FabLab introduction, 3D modeling using Tinkercad, hands-on 3D printing, mentoring, and reflection. The activities were designed to connect teachers' understanding of digital fabrication with direct experience in designing and developing learning media. The participants were 23 chemistry teachers from Bandar Lampung. The training began with an introduction to FabLab and digital fabrication, including an explanation of the concept, workflow, and potential application of 3D technology in chemistry learning. This session provided participants with an initial understanding of how digital fabrication can be integrated into the development of innovative learning media.



Figure 2. Introduction to FabLab and digital fabrication for chemistry learning

Following the introduction, participants were guided through hands-on practice using Tinkercad to design three-dimensional learning objects. Participants explored basic modeling features and were encouraged to develop objects that could potentially be used to support the visualization of chemistry concepts.

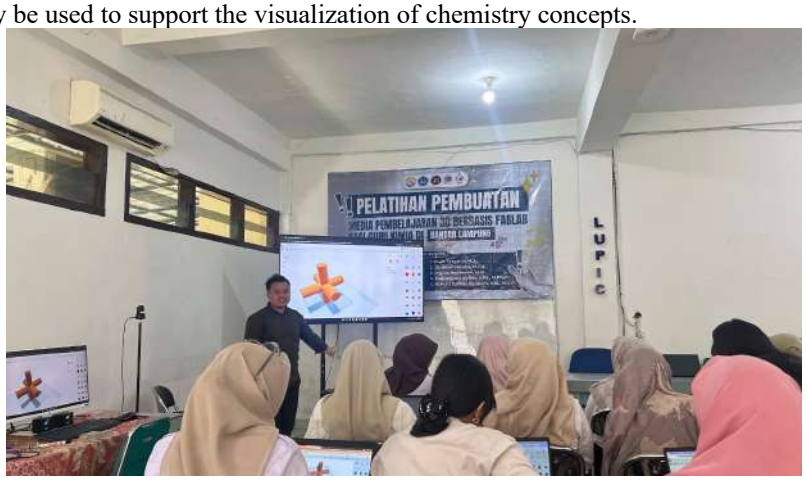
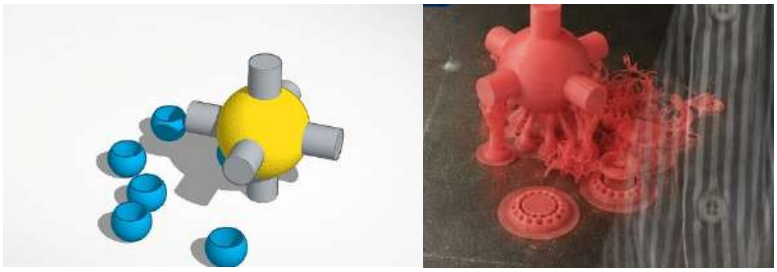


Figure 3. Participants practicing 3D modeling using Tinkercad

The modeling activity allowed participants to directly experience the process of transforming an instructional idea into a digital three-dimensional design. One example of the 3D learning media design developed during the activity is presented in Figure 4.



a. 3D media design b. Physical object after 3D printing

Figure 4. Example of a 3D learning media design developed using Tinkercad

The training then continued with mentoring and hands-on practice related to the 3D printing process. Participants were guided to understand how a digital design can be prepared and transformed into a physical learning object. The activity concluded with reflection on the knowledge, technical skills, and potential classroom applications gained during the training. Overall, the sequence provided participants with an integrated experience of understanding, designing, making, and reflecting. This was important because the training was not limited to introducing FabLab and 3D printing technology, but also provided teachers with direct experience in developing learning media. The process enabled participants to recognize the potential of digital fabrication for making abstract chemistry concepts more tangible and supporting classroom learning. One participant reflected:

> "The hands-on experience of transforming digital designs into physical products provides a tangible understanding of technology implementation."

This response illustrates that direct experience was an important component of the training. Rather than learning about digital fabrication only theoretically, participants were involved in the process of developing a learning object from the initial design stage toward its potential physical application. Thus, the training provided not only technological knowledge but also an initial experience of integrating FabLab-based fabrication into chemistry learning.

Teachers' Cognitive Readiness in Understanding FabLab and Digital Fabrication

The first objective of the community service program was to strengthen teachers' understanding of FabLab and digital fabrication. The reflective responses indicated that participants developed new understanding of the concept, workflow, and educational potential of digital fabrication. Several participants explicitly described that their previous knowledge of 3D printing was limited to information obtained from the internet or social media. After participating in the training, they reported understanding the process from design to production. One participant explained that before the training, 3D printing was known only as information, while the training enabled them to understand the actual production process and its application in classroom learning. The QCA identified knowledge improvement in 23 of 23 participants (100%). Thus, all participants' responses contained evidence of gaining or expanding knowledge related to FabLab and digital fabrication. This finding provides direct evidence that the first objective of the community service activity was reflected in participants' experiences.

Table 2. Cognitive readiness identified from participant reflections

Indicator	Frequency	Percentage
Knowledge improvement	23/23	100.00%

The finding is consistent with the problem identified before the intervention, namely the limited familiarity of chemistry teachers with FabLab concepts and digital fabrication. Khefrianti et al. (2024) reported that chemistry teachers' awareness and understanding of FabLab remain important issues in the adoption of transformative educational practices.

The result also supports the view of Saputra and Chaeruman (2022) that technology integration in education requires teachers to possess knowledge that connects professional expertise, pedagogy, and technology. In the present activity, this connection began with teachers understanding what FabLab is, what digital fabrication can produce, and why the technology may be relevant to chemistry learning.

Development of Teachers' Technical Skills in 3D Design and Fabrication

The second objective focused on developing teachers' technical skills in designing 3D learning media. The training provided direct practice using Tinkercad and introduced participants to the process of preparing designs for 3D printing. The QCA showed that 23 of 23 participants (100%) expressed evidence of technical learning or skill development.

Table 3. Technical readiness identified from participant reflections

Indicator	Frequency	Percentage
Technical skill improvement	23/23	100.00%

The qualitative responses provide stronger evidence of what this technical learning involved. Participants described learning to design three-dimensional objects, prepare files, understand printing parameters, and recognize that a digital design does not automatically produce a successful physical product. One participant explained that the experience involved learning the workflow from design to printing and understanding the importance of size, material, printing parameters, and iterative improvement. Another participant specifically described the experience of designing an SF_6 molecule using Tinkercad and subsequently seeing the design printed as a physical model.

This finding is important because the technical outcome was not limited to operating a printer. Participants began to understand the relationship between digital design and physical fabrication. The experience also introduced an iterative design process in which errors or unsuccessful designs become opportunities for modification.
The finding is consistent with the maker-oriented nature of FabLab, where designing, prototyping, testing, and improving products constitute an important part of the learning process.

Teachers' Ability to Produce 3D Learning Media
The third objective was to provide teachers with direct experience in producing 3D-printed learning media. The most important evidence was participants' descriptions of the transition from digital designs to tangible objects. Participants repeatedly identified the printing process as one of the most meaningful parts of the training. One participant described the experience of seeing an SF_6 model gradually emerge from the 3D printer and emphasized that the process changed the way the participant viewed the potential of physical learning media. The experience was not simply technical. Participants began to recognize that the physical product could function as a learning resource for abstract chemistry concepts. For example, participants proposed using printed models for molecular geometry, VSEPR, crystal structures, atomic orbitals, and chemical bonding. One participant proposed using models of CH_4, NH_3, H_2O, BF_3, PCl_5, and SF_6 so that students could assemble and analyze molecular geometry, bond angles, and polarity.

Thus, the training moved beyond the objective of "being able to print" toward "being able to produce an instructional object with a pedagogical purpose." This distinction is important. Previous studies have established the potential of 3D printing for chemistry education, particularly for visualizing molecular structures (Pernaa & Wiedmer, 2020; Pinger et al., 2020). The present activity extends this perspective to teacher professional development by placing teachers directly in the position of designer and producer of the learning media.

Teachers' Readiness to Integrate 3D Media into Chemistry Learning
The reflections also demonstrated that participants did not perceive 3D media merely as technological products. They connected the media with specific chemistry topics and classroom activities. The QCA identified three major pedagogical and implementation patterns: connecting 3D media with chemistry content, designing student-centered activities, and planning concrete classroom applications. Pedagogical readiness reached 98.91%, while implementation readiness reached 100% based on the coded responses.

Table 4. Pedagogical and implementation readiness

Dimension	Frequency	Percentage
Pedagogical readiness	91/92	98.91%
Implementation readiness	46/46	100.00%

The participants proposed concrete applications rather than expressing only general interest. For example, teachers proposed using 3D molecular models for VSEPR learning, in which students would assemble molecular structures, identify molecular geometry, determine bond angles, and analyze polarity. Other proposed applications included crystal structures, atomic orbitals, ionic bonding, and carbon structures.
One participant stated:

> "I will use 3D-printed objects as a learning aid for the topic of Molecular Geometry—based on VSEPR theory—in a tenth-grade class."

The participant further proposed that students work in groups to assemble models and analyze the relationship between electron pairs, molecular geometry, and polarity. These responses demonstrate that participants were beginning to connect technology → chemistry content → learning activity, which is central to meaningful technology integration.
This finding strongly relates to the TPACK framework of Mishra and Koehler (2006), in which effective technology integration occurs when technological knowledge is connected with pedagogical and content knowledge. Saputra and Chaeruman (2022) similarly emphasized the importance of the relationship between technology, pedagogy, and professional knowledge in technology-integrated education.

Quantitative Content Analysis of Participants' Reflections
The participants' reflections were further synthesized into five dimensions: cognitive, technical, pedagogical, implementation, and psychological readiness. The analysis represents the proportion of participants whose responses contained evidence of each indicator, rather than a standardized test score or experimental measurement.

Table 5. Teachers' readiness based on readiness dimensions

Readiness Dimension	Constituent Indicators	Frequency	Percentage (%)	Category
Cognitive readiness	Knowledge improvement	23/23	**100.00**	Very High
Technical readiness	Technical skill improvement	23/23	**100.00**	Very High
Pedagogical readiness	Pedagogical insight, lesson planning, learning activity design, student-centered learning	91/92	**98.91**	Very High
Implementation readiness	Perceived usefulness, implementation readiness	46/46	**100.00**	Very High
Psychological readiness	Professional self-development, meaningful learning experience, perceived advantages, change in teaching perspective, motivation	114/115	**99.13**	Very High

The synthesis indicates that responses were consistently concentrated across the five dimensions. Cognitive, technical, and implementation indicators appeared in all relevant coded responses, while pedagogical and psychological dimensions showed only very small differences from complete coverage. The psychological dimension reached 99.13%, reflecting participants' descriptions of meaningful experiences, changes in perspective, motivation, and willingness to continue developing technology-based learning media. Importantly, these results should be interpreted as evidence emerging from participants' reflections, not as proof of causal improvement. The high percentages indicate that the intended outcomes of the training were strongly represented in participants' responses. Figure 5 illustrates the percentage of teacher readiness across the five dimensions identified through quantitative content analysis.

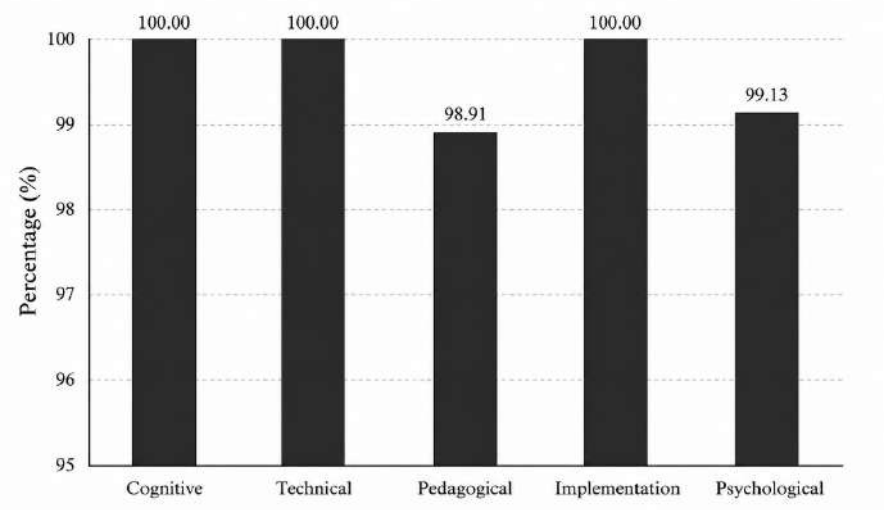


Figure 5. Percentage of teacher readiness across five dimensions after FabLab-based training

Figure 5 clearly demonstrates that all readiness dimensions exceeded 98%, indicating that the FabLab-based training produced balanced improvements across teachers' knowledge, technical competence, pedagogical capability, implementation confidence, and psychological readiness. The relatively small variation among dimensions suggests that the training successfully combined theoretical understanding with practical experience, enabling participants to develop comprehensive competencies necessary for integrating 3D learning media into chemistry classrooms.

Discussion: FabLab, TPACK, and Chemistry Teacher Professional Development

The findings of the community service program demonstrate that the FabLab-based training achieved the three initial objectives of the program. Participants reported gaining an understanding of FabLab, acquiring experience in 3D design and fabrication, and identifying concrete ways to utilize 3D-printed learning media in chemistry instruction. These findings also support the TPACK perspective. The training did not position 3D printing merely as an isolated technological skill. Instead, participants were encouraged to connect the technology with chemistry content and classroom pedagogy. The proposed applications, including VSEPR theory, molecular geometry, crystal structures, and chemical bonding, indicate the emerging integration of technological knowledge with pedagogical needs in chemistry education. This finding is consistent with Saputra and Chaeruman (2022), who emphasized the importance of integrating technology with professional and pedagogical knowledge in technology-based learning.

The findings are also consistent with previous studies on 3D printing in chemistry education. Pernaa and Wiedmer (2020) identified the potential of 3D printing to support the visualization of chemical structures, while Pinger et al. (2020) demonstrated the application of 3D-printed models in chemistry education. A distinctive feature of the present community service program is that teachers themselves were trained to design, produce, and potentially utilize 3D learning media in their chemistry classrooms. This activity also differs from conventional technology training because participants experienced the entire process, beginning with FabLab introduction, followed by digital design, fabrication, production of physical objects, and pedagogical reflection. This integrated sequence enabled teachers to understand not only how the technology works, but also why and how it can be applied to chemistry learning.

The primary data also indicated a change in participants' perceptions. Before the training, some participants described their knowledge of 3D printing as being limited to information obtained from the internet or social media. After directly experiencing the design and printing processes, they began to perceive 3D printing as an alternative for representing abstract chemistry concepts. This is particularly relevant to chemistry education because concepts such as molecular geometry and crystal structures require spatial visualization. The novelty of this community service program does not lie in the use of 3D printing itself, which has been widely reported in previous studies, but rather in the integration of FabLab-based teacher professional development, hands-on 3D design and fabrication, chemistry-specific pedagogical planning, and Quantitative Content Analysis (QCA) of participants' reflections as primary evidence. This approach positions teachers not only as users of technology but also as potential creators of learning media that can be adapted to specific instructional needs. These findings further reinforce the importance of professional development that provides direct practical experience rather than merely demonstrating technology. Participants' reflections indicate that transforming a digital design into a physical object was one of the influential experiences in shaping their understanding of the pedagogical potential of 3D learning media.

4. CONCLUSION

This community service program successfully enhanced the readiness of chemistry teachers in Bandar Lampung to develop and implement FabLab-based three-dimensional (3D) learning media. The integration of conceptual learning, digital design practice, and hands-on 3D printing activities enabled participants to acquire comprehensive competencies to support technology-based chemistry instruction. Quantitative content analysis revealed that the teachers' overall readiness reached 99.61%, placing it in the "very high" category. These findings indicate that the training successfully improved the teachers' understanding of FabLab. Beyond enhancing individual competence, the training also fostered a shift in teachers' perceptions regarding the role of digital fabrication in education. Participants recognized that 3D-printed learning media could provide more meaningful visualizations of abstract chemical concepts compared to conventional media and support student-centered learning. Implications for future initiatives include the need for FabLab training for the broader educational community, the establishment of teacher innovation networks, and ongoing mentoring to support the long-term implementation of digital fabrication technology in schools. Future research is also recommended to examine the impact of FabLab-based learning media on students' conceptual understanding, scientific literacy, creativity, and higher-order thinking skills.

ACKNOWLEDGMENT

The authors extends their gratitude to the Faculty of Teacher Training and Education at the University of Lampung for supporting this community service activity, the FabLab management team, and all the chemistry teachers from Bandar Lampung who actively participated in the training.

5. REFERENCES

Coe, K., & Scacco, J. M. (2017). Content analysis, quantitative. In J. Matthes, C. S. Davis, & R. F. Potter (Eds.), *The international encyclopedia of communication research methods* (pp. 346–356). Wiley. https://doi.org/10.1002/9781118901731.iecrm0045

Dean, J., Ewan, C., & McIndoe, J. S. (2016). Applying hand-held 3D printing technology to the teaching of VSEPR theory. *Journal of Chemical Education, 93*(9), 1660–1663. https://doi.org/10.1021/acs.jchemed.6b00186

Ford, S., & Minshall, T. (2019). Invited review article: Where and how 3D printing is used in teaching and education. *Additive Manufacturing, 25*, 131–150. https://doi.org/10.1016/j.addma.2018.10.028

Khefrianti, S., Rustaman, N., Kadarohman, A., & Wiji. (2024). Exploring chemistry teachers' awareness of FabLab for transformative educational practices. *EduChemia: Jurnal Kimia dan Pendidikan, 9*(2), 188–204. https://doi.org/10.30870/educhemia.v9i2.24418

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record, 108*(6), 1017–1054. https://doi.org/10.1111/j.1467-9620.2006.00684.x

Niece, B. K. (2019). Custom-printed 3D models for teaching molecular symmetry. *Journal of Chemical Education, 96*(9), 2059–2062. https://doi.org/10.1021/acs.jchemed.9b00053

Pernaa, J., & Wiedmer, S. (2020). A systematic review of 3D printing in chemistry education—Analysis of earlier research and educational use through technological pedagogical content knowledge framework. *Chemistry Teacher International, 2*(2), 20190005. https://doi.org/10.1515/cti-2019-0005

Pinger, C. W., Geiger, M. K., & Spence, D. M. (2020). Applications of 3D-printing for improving chemistry education. *Journal of Chemical Education, 97*(1), 112–117. https://doi.org/10.1021/acs.jchemed.9b00588

Renner, M., & Griesbeck, A. (2020). Think and print: 3D printing of chemical experiments. *Journal of Chemical Education, 97*(10), 3683–3689. https://doi.org/10.1021/acs.jchemed.0c00416

Saputra, B., & Chaeruman, U. A. (2022). Technological pedagogical and content knowledge (TPACK): Analysis in design selection and data analysis techniques in high school. *International Journal of Instruction, 15*(4), 777–796. https://doi.org/10.29333/iji.2022.15442a

Sheridan, K., Halverson, E. R., Litts, B. K., Brahms, L., Jacobs-Priebe, L., & Owens, T. (2014). Learning in the making: A comparative case study of three makerspaces. *Harvard Educational Review, 84*(4), 505–531. https://doi.org/10.17763/haer.84.4.brr34733723j648u

Trujillo-Cayado, L. A., Santos, J., Cordobés, F., & Ramos-Payán, M. (2024). Influence of the use of 3D printing technology for teaching chemistry in STEM disciplines. *Computer Applications in Engineering Education, 32*(4), e22738. https://doi.org/10.1002/cae.22738