SEARCH: Science Education Research Journal
Volume 5, Issue 2
E-ISSN: 3032-6435
https://doi.org/10.47945/search.v5i2.3442

Needs Analysis for Developing a Teams Games Tournament-Based Student Worksheet on Atomic Structure

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Abstract

This study examined the need for developing a student worksheet based on the Teams Games Tournament (TGT) cooperative learning model for atomic structure. It represents the preliminary research phase of an educational design research project guided by the Plomp model. An embedded mixed-methods approach involved two chemistry teachers and 60 tenth-grade students from SMAN 1 Batang Anai and SMAN 2 Batang Anai. Data were collected through semi-structured teacher interviews, an 11-item yes/no needs-analysis questionnaire, and a 10-item multiple-choice comprehension test. Interview findings indicated that the worksheets currently used mainly contained material summaries and practice questions and did not incorporate team tournaments. Questionnaire responses showed that 82% of students felt that the existing worksheets had not helped them understand the material; 95% reported that group learning made the material easier to understand, 95% were more motivated when games were included, and 94% were more enthusiastic when groups competed. Test performance was lowest on items concerning the Pauli exclusion principle (31.7% correct), the Aufbau principle (36.7%), and Hund's rule (45.0%); the mean test score was 56.0. These findings provide a preliminary basis for designing a TGT-based worksheet with scaffolded conceptual practice, visual representations, collaborative games, and reflection. The study identifies learning needs and does not evaluate the validity or effectiveness of a developed product.

Article History:
Received 05/10/ 2026
Accepted 29/11/ 2026

Keyword:
Atomic structure; Needs analysis; Student worksheet; Teams Games Tournament.

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How to Cite: Dongoran, L., & Syolendra, D. finna. (2026). Needs Analysis for Developing a Teams Games Tournament-Based Student Worksheet on Atomic Structure. SEARCH: Science Education Research Journal, 5(2), 337–344. https://doi.org/10.47945/search.v5i2.3442

INTRODUCTION

Chemical literacy requires students to understand chemical concepts and use that understanding to interpret phenomena and solve problems. This expectation can be challenging because chemistry involves concepts that are not always directly observable, including the structure and behavior of atoms (Ambarwati et al., 2023). Atomic structure is a foundational topic, but students must learn to reason about entities at the submicroscopic level and connect them with symbolic representations such as atomic notation, electron configurations, and orbital diagrams. Studies of secondary-school learners have reported misconceptions about atomic models, subatomic particles, isotopes, and electron configurations (Herdien & Bahriah, 2024; Nufus & Silfianah, 2023).

One particularly demanding part of atomic structure is the relationship among electron configurations, orbital filling rules, and quantum numbers. Students must understand the order in which orbitals are filled, apply the Pauli exclusion principle, use Hund's rule, and interpret the four quantum numbers. These ideas are related rather than isolated: a decision about electron placement affects the orbital diagram and the quantum-number description. Research has documented difficulties in interpreting quantum concepts and constructing electron configurations, including cases in which students rely on simplified or classical mental models of the atom (Nugroho&

Prayitno, 2023). Such difficulties are important because misunderstandings in foundational representations can affect subsequent chemistry learning.

From a cognitive perspective, learning atomic structure requires students to coordinate submicroscopic models with symbolic notations and formal rules. For novice learners, processing several unfamiliar representations and constraints at the same time may place substantial demands on working memory. Chemistry instruction therefore needs to sequence new information, activate prerequisite knowledge, provide worked examples, and allow students to practise procedures until key relationships become more accessible. Visual and manipulable representations may also help learners connect abstract models with more concrete forms of explanation. Recent studies have explored interactive games and low-cost atomic models as ways to support learning about electron configuration and molecular structure (Goldman et al., 2024; Iyamuremye et al., 2025).

Student worksheets can organize learning activities, guide students through conceptual steps, and provide opportunities for practice. However, a worksheet that mainly presents summaries and routine exercises may not sufficiently support students who need visual explanations, guided practice, feedback, and discussion. A needs analysis conducted by Nofriyanti and Hardeli (2023), for example, identified students' interest in more active worksheet-based learning on atomic structure. In a related development study, Putri and Alizar (2025) reported the validity of a TGT-based worksheet for atomic structure. These studies show that worksheet development and TGT integration have already received attention; therefore, the present study does not claim that a TGT-based atomic-structure worksheet has never been developed.

Game-based learning may offer a way to structure practice and feedback while maintaining student participation. A systematic review in chemistry education found that game-based learning has been used to support conceptual understanding and motivation, while a three-level meta-analysis reported positive average effects on cognitive and motivational outcomes but also noted variation across studies and designs (Byusa et al., 2022; Hu et al., 2022). A broader meta-analysis similarly indicates that the effects of gamification depend on how game elements are designed and combined with collaboration (Sailer & Homner, 2020). Game elements should therefore serve the learning objectives rather than become an end in themselves. Research on gameful learning also highlights the importance of autonomy, competence, and meaningful participation (Jones et al., 2023).

The Teams Games Tournament (TGT) model combines team study, academic games, and tournaments. In chemistry education, previous studies have reported its use to support student activity, interest, or learning outcomes (Agustina et al., 2020; Puspareni et al., 2024; Rivaldo et al., 2024; Sundari et al., 2023). A recent review has also discussed the use of TGT with digital interactive media (Dita & Armiati, 2025). Nevertheless, the presence of a game or competition does not automatically address conceptual difficulties. For atomic structure, tournament questions need to be arranged in a progression that helps students move from basic representations to more demanding applications of electron-filling rules and quantum numbers. Group work also needs individual accountability so that each learner engages with the concepts.

This study addresses a contextual and design-oriented gap: prior Teams Games Tournament (TGT) atomic-structure worksheets (Putri & Alizar, 2025) do not substitute for a site-specific needs analysis at SMAN 1 and SMAN 2 Batang Anai. Using preliminary interviews, a questionnaire, and a comprehension test, it links current worksheets, student preferences, and test performance—especially around electron configuration and quantum numbers—to examine difficulties and stakeholder views on team competition in atomic-structure learning.

RESEARCH METHODS

This study forms part of an educational design research project guided by the Plomp model, which includes preliminary research, prototyping, and assessment phases (Plomp & Nieveen, 2013). The present article reports only the preliminary research phase. Its purpose is to identify the learning problems, classroom conditions, and user needs that can inform the design of a worksheet in the subsequent prototyping phase. The study used an embedded mixed-methods approach: qualitative information was obtained through semi-structured interviews with chemistry teachers, while quantitative information was obtained through a student questionnaire and a multiple-choice comprehension test. The three sources were considered together to compare teacher perspectives, student perceptions, and students demonstrated responses to atomic-structure questions. The participants were two chemistry teachers and 60 tenth-grade students from SMAN 1 Batang Anai and SMAN 2 Batang Anai. The student group consisted of two classes, with 30 students from each school.

Three instruments were used. First, a semi-structured interview guide was used to obtain information from the two chemistry teachers about the atomic-structure content taught, the learning materials used, students difficulties, and the teachers views on cooperative and tournament-based learning. Second, a student needs-analysis questionnaire contained 11 statements with yes/no response options and was described in the source manuscript as using a Guttman scale. Third, a 10-item multiple-choice test assessed students' grasp of atomic structure across atomic models, atomic and mass numbers, ion subatomic particles, isotopes/isobars/isotones, electron configuration, orbital-filling rules, and quantum numbers.

Interview data were analysed using the interactive process of data reduction, data display, and conclusion drawing/verification described by Miles et al. (2014). Responses from the two teachers were compared to identify recurring patterns in the reported learning materials, student difficulties, and possible instructional responses. Questionnaire responses and test results were analysed descriptively. For each questionnaire statement, the percentage of yes and no responses was calculated using the number of students selecting each response divided by the total number of respondents and multiplied by 100. For the comprehension test, the percentage of correct answers for each item was calculated using the number of students answering correctly divided by 60 and multiplied by 100. The overall mean, median, minimum, and maximum test scores were reported as available in the source manuscript.

The source manuscript provided for revision does not contain records of expert validation, pilot testing, item analysis, or reliability coefficients for the questionnaire and comprehension test. Accordingly, this revised manuscript does not report a content-validity index, item-validity coefficient, Cronbach's alpha, or other psychometric statistic, and it does not claim that the instruments were empirically validated or shown to be reliable. The instruments are treated as preliminary descriptive tools, and this limits the strength of inferences that can be drawn from their results. Formal validation and reliability testing should be completed and documented before the instruments are reused or used to support high-stakes conclusions.

The source manuscript also does not state the institutional permission procedure, ethics approval information, or how informed consent was obtained from participating teachers, students, and, where applicable, their parents or guardians. No approval number or consent procedure has therefore been inserted or assumed in this revision. These details should be verified from the schools and the researchers' records and reported accurately before journal submission.

RESULTS AND DISCUSSION

The interviews with the chemistry teachers at SMAN 1 Batang Anai and SMAN 2 Batang Anai indicated that atomic structure was taught in Grade 10 during the first semester. The topics covered ranged from the historical development of atomic theory to electron configuration. The learning materials included PowerPoint presentations and student worksheets. Although some worksheets were associated with discovery learning, the teachers described their content as being dominated by material summaries and practice questions. Both teachers identified writing electron configurations and determining quantum numbers as the most difficult parts of the topic. They estimated that approximately 40–50% of students experienced difficulty with these subtopics.

Both teachers had used group learning, but not a cooperative learning format specifically organized around team tournaments. They also reported positive classroom experiences with interactive quiz applications such as Kahoot and Quizizz, which they perceived as encouraging student enthusiasm and participation. The teachers considered a TGT-based worksheet potentially useful, provided that its implementation took account of lesson duration, group size, and classroom management so that participation would not be limited to a small number of students.

The needs analysis questionnaire was completed by 60 students from SMAN 1 and SMAN 2 Batang Anai. A summary of the questionnaire results is presented in Table 1.

Table 1. Summary of student questionnaire results

Statement	Yes	No
Teachers use LKPD during lessons	97%	3%
The LKPD used contains only practice questions and material summaries	95%	5%
The LKPD used has helped me understand the material well	18%	82%
I have difficulty understanding the material because of the many concepts	81%	19%
I feel bored when learning consists only of listening to the teacher's explanation	83%	17%
I feel able to understand the material when it is explained in an interesting way	96%	4%
I remain enthusiastic about learning even when the material is difficult	18%	82%
I understand the material more easily when learning in groups	95%	5%
I am more motivated to learn when there are game elements	95%	5%
Competition between groups makes me more enthusiastic about learning	94%	6%
Fun learning makes me more active and understand faster	93%	7%

The comprehension test consisted of 10 questions covering five competencies in the atomic structure material and was taken by 60 students. The achievement for each question is presented in Table 2.

Table 2. Results of comprehension test analysis by question indicator

Question indicator	Number Correct	Percentage
Thomson atomic model	41	68.3
Conclusion of Rutherford's alpha-particle scattering experiment	39	65
The weakness in Rutherford's model that Bohr fixed	40	66.7
Determining atomic and mass numbers from protons and neutrons	40	66.7
Determining protons, neutrons, and electrons in an Al^{3+} ion	32	53.3
Relationship among isotopes, isobars, and isotones between atoms	30	50
The concept of isotones (equal number of neutrons)	45	75
Finding valid quantum numbers based on Pauli's principle	19	31.7
Filling degenerate orbitals using Hund's rule	27	45
Arranging electron configurations based on the Aufbau principle	22	36.7

Table 2 shows that students' achievement in understanding atomic models (items 1–3) and

atomic notation/isotones (items 4 and 7) is fairly good, with achievement percentages ranging from 65–75%. However, achievement drops sharply in the aspects requiring more complex reasoning, namely determining quantum numbers based on the Pauli exclusion principle (31.7%), electron configuration based on the Aufbau principle (36.7%), and electron filling based on Hund's rule (45.0%). This pattern is consistent with the teacher interviews, which indicated that electron configuration and quantum numbers are the sub-topics students find most difficult to understand. Overall, the 60 students' comprehension test scores had a mean of 56.0, with a highest score of 80 and a lowest score of 20. The distribution of student scores is presented in Figure 1.

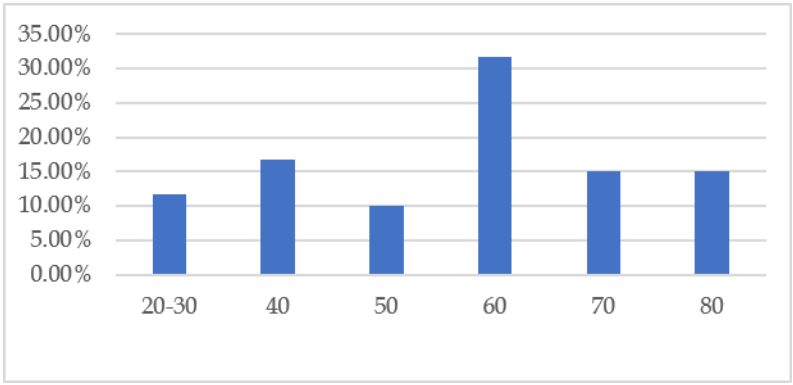

Figure 1. Distribution of test scores

The mean comprehension test score was 56.0, with a median of 60.0, a minimum score of 20, and a maximum score of 80. A total of 42 of the 60 students (70%) obtained scores below 70, indicating that most students' mastery of atomic structure concepts is still below the level expected for prerequisite material in subsequent chemistry learning.

The data from the teacher interviews, the student questionnaire, and the comprehension test show findings that reinforce one another. The teachers judged that the LKPD in use does not yet fully encourage student activeness because it is still oriented toward practice questions, and students perceived this similarly: 82% stated that the LKPD had not helped their understanding. The difficulties in the sub-topics of electron configuration and quantum numbers reported by the teachers were also confirmed quantitatively by the low percentages of correct answers on the related indicators of the diagnostic test (31.7–45.0%).

Meanwhile, the high percentages of students who were motivated by game elements (95%), group competition (94%), and enjoyable learning (93%) are in line with the teachers' positive experiences when using game-based quizzes such as Kahoot and Quizizz. These findings are consistent with the systematic review by Byusa et al. (2022), which found that game-based learning in chemistry education can increase motivation and conceptual understanding. Meta-analytic evidence also shows that gamification has positive effects on cognitive, motivational, and behavioral learning outcomes, although the size of the effect differs depending on the design and context of implementation (Bai et al., 2020; Hu et al., 2022; Sailer & Homner, 2020). In addition, the application of game-assisted TGT has been reported to increase student activeness in chemistry learning (Rivaldo et al., 2024). The consistency of these findings strengthens the argument that the TGT cooperative model, which combines teamwork, games, and academic tournaments, fits the characteristics and needs of students in learning atomic structure. The development of a TGT-based LKPD with a deep learning approach is expected to address the gap between the teaching materials currently available and students' need to learn actively, collaboratively, and meaningfully, while also helping to overcome the conceptual difficulties in the sub-topics of quantum numbers and electron configuration identified through the comprehension test.

The finding that the available LKPD has not helped students understand atomic structure is in line with previous research, because conventional teaching materials are indeed often less effective for abstract topics such as electron configuration and quantum numbers (Iyamuremye et al., 2025; Nilawati et al., 2025). Research by Nofriyanti and Hardeli (2023) found that 38% of tenth-grade students considered the teaching materials used for atomic structure not helpful for their understanding, and 95% of students were interested in LKPD based on more active learning. The figure of 82% in this study is higher than the finding of Nofriyanti and Hardeli, which may be due to differences in the scope of the sub-topics tested. This study covers material up to electron configuration and quantum numbers, which demand higher abstract reasoning, while the mismatch of teaching materials is usually felt more strongly in more complex sub-topics. Students' mastery of electron configuration and quantum numbers has indeed been reported to be the lowest compared with other atomic structure indicators (Kisdiono, 2023).

The students' difficulties in the sub-topics of electron configuration, the Aufbau principle, the Pauli exclusion principle, and Hund's rule found in this study are also consistent with a number of studies on atomic structure misconceptions, which generally report that these sub-topics are a source of misconceptions with fairly high percentages among senior high school students, with some even reporting average student difficulty above 70% on concepts related to electron configuration and the periodic system. This consistency across studies strengthens the argument that the difficulty in these sub-topics is systemic rather than merely a local characteristic of the two schools studied. Meanwhile, students' positive responses to competition and group work elements are in line with a number of studies applying the TGT model in chemistry learning, which report increases in student motivation, activeness, or learning outcomes after the model was applied to various senior high school chemistry topics. However, those studies are generally at the implementation or experimental stage, whereas this study is only at the stage of identifying needs before a product is developed, so the claims that can be made are limited to indications of need and potential, not evidence of effectiveness.

CONCLUSION

This preliminary needs analysis indicates that the worksheets used in SMAN 1 Batang Anai and SMAN 2 Batang Anai do not fully match students' reported learning needs in atomic structure. Although worksheets were used in lessons, most students described them as dominated by summaries and practice questions, and 82% indicated that they had not helped their understanding. Students reported that group learning, games, and intergroup competition could make learning more engaging. The comprehension test also identified electron configuration and the rules governing electron placement particularly the Pauli exclusion principle, the Aufbau principle, and Hund's rule as areas requiring additional instructional support.

The contribution of this study is a topic-specific needs map based on teacher interviews, student questionnaire responses, and comprehension-test results. The map provides a focused basis for the next phase of developing a TGT-based worksheet. The prototype should connect visual and symbolic representations, scaffold the application of electron-filling rules, include collaborative games and tournaments with individual accountability, provide immediate explanatory feedback, and encourage reflection after the tournament. These are design recommendations rather than tested outcomes. Further research is required to establish instrument quality, document ethical procedures, and evaluate the validity, practicality, and learning effects of the developed worksheet.

ACKNOWLEDGMENTS

The authors express their gratitude to Ibu Dwi Finna Syolendra, the supervising lecturer, for her guidance in preparing this article. Thanks are also extended to Ibu Winda, chemistry teacher at SMA N 1 Batang Anai, and Ibu May Fitri Yeni, chemistry teacher at SMA N 2 Batang Anai, as well as all the students who contributed to the data collection for this article. May all their help and kindness be repaid with due reward by Allah SWT.

AUTHOR CONTRIBUTIONS

The first author was responsible for data collection, data management, and writing the research article. The second author was responsible for supervision, providing guidance, and reviewing and revising the research article. All authors have read, provided feedback on, and approved the article for publication.

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